STUDY OF CONVENTIONAL TILE FIELDS IN FINE-GRAINED SOILS

REPORT NO. 74

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Ministry of the Environment
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IN FINE-GRAINED SOILS

By:

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ABSTRACT

In this project, a total of twelve existing tile fields constructed in fine-grained soils (silts and clays) were studied. Different methods, such as the field percolation test, the laboratory hydraulic conductivity test, the particle size distribution test were examined as to their usefulness for the evaluation of the suitability of the soils for the construction of tile fields. The performance of the tile fields was studied in the field and was related to the soil drainage characteristics and other design factors. From the field investigations, conclusions were drawn regarding the validity of different techniques for assessing soil drainage characteristics and also, some guidelines pertaining to designing the conventional tile fields were proposed.

ACKNOWLEDGEMENTS

The field investigations presented in this report were carried out on twelve private properties. The assistance and co-operation of the property owners throughout the study are gratefully acknowledged.

PROJECT STAFF

The following staff of the Applied Sciences Section were instrumental in the production of this report:

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1. INTRODUCTION

In Ontario, a large portion of the land is underlain by fine-grained soils, (e.g. silts and clays) which may or may not be suitable for the installation of conventional septic tank-tile field systems as far as the infiltrative capacity of the soils is concerned. As more soils with good infiltrative capacity are used up for new tile field systems, it is becoming necessary, in many instances, to construct systems in less permeable fine-grained soils. At present, the ability for evaluating the suitability of fine-grained soils is still quite limited. Basically, two methods are used by the field staff of the Ministry of the Environment and the county health units to assess the soils:

(i) The soils are visually examined in the field for their suitability. The successful use of this method depends, to a large extent, on the experience of the field personnel, and on the correlation between the soil conditions and the performance of other tile fields in similar soils. The interpretation of the on-site soil conditions is subjective and could be erroneous if the experience of the field technician is limited. In some instances, laboratory tests, such as grain size distribution, plasticity, hydraulic conductivity (permeability), etc. are used to complement and/or supplement the field information.

In the case of fine-grained soils, it is very difficult to assess the suitability of the material on the basis of field inspections normally on disturbed soil samples obtained in small-diameter augered holes. Furthermore, laboratory data on disturbed fine-grained soils are of limited value because the correlation of laboratory results and the on-site infiltrative capacity of the soil is poor (Chan, 1975).

(ii) The suitability of the soil is evaluated by the field percolation test, which was originally devised by Ryon, (Federick, 1948; MOE., 1974). If the percolation time ("t" time) of the soil is smaller than 24 min./cm (60 min./in.), the soil is considered acceptable for the construction of the conventional tile field. This arbitrary percolation test limit is widely used by many regulatory agencies in North America, but its applicability is questionable because some fine-grained soils with percolation time exceeding this time limit apparently have adequate infiltrative capacity for the septic tank effluent.

Because there are limitations in the existing methods and because there are needs for more knowledge and experience in evaluating the suitability of fine-grained soils for installing tile fields, a project was initiated with the following objectives:

(i) To evaluate the existing methods for assessing the suitability of fine-grained soils, and using the field data, to point out the feasibility and limitations of such methods.

(ii) To investigate the factors affecting the performance of tile field systems in fine-grained soils so that guidelines for the design and construction of such systems can be proposed.

(iii) To study the possibility of using information from existing soil maps for the evaluation of soil suitability.

2. OUTLINE OF FIELD AND LABORATORY INVESTIGATIONS

A total of twelve existing tile-field systems located in fine-grained soils were studied to obtain data pertaining to the performance of the systems and the soil conditions. A group of six systems and another group of four systems were located in two subdivisions developed several years ago and the remaining two systems were for two isolated houses. All sites were located between Toronto and Barrie. It was intentional to select a number of systems located in the same subdivision so that some of the factors governing the performance of the systems were identical.

On each site, a number of studies were done and they are briefly discussed as follows:-

(i) Soil borings were made with a 3-cm diameter hand auger to determine the stratigraphy of the subsoil in and around the tile field area. If the soils were not fine-grained soils, the potential site would be rejected. Otherwise, soil samples would be obtained from the site for laboratory identification and classification tests.

(ii) The topography of the site was surveyed so that the surface drainage conditions would be determined.

(iii) Percolation tests were performed to determine the percolation time ("t" time) of the soil. The diameter of the hole was 10 cm (4 in.) and the depth of the hole was approximately the same as the depth of the tile trench. The soil around the hole was soaked for approximately 24 hours with water put in the hole to a minimum depth of 30 cm (1 ft.). When the percolation time was measured, the height of the water column was 15 cm (6 in.) above the 5 cm thick gravel layer which was initially placed at the bottom of the hole. The details of testing and the equipment used can be found in the Ministry publications (MOE., 1974; Chan, 1976).

(iv) Several pieces of "undisturbed" block soil samples were obtained in a shallow excavation (about 1 m deep) and were tested for hydraulic conductivity characteristics in the soils laboratory.

(v) The information was obtained regarding the design of the septic tank-tile field system (i.e. the size of the septic tank, the total length, the depth and the spacing of the tiles). If available, the drawing of the system was obtained from the county health unit for reference. In addition, at each site the location and the depth of the tiles were determined by probing with a steel rod or a hand auger 3 cm in diameter.

(vi) The water consumption rate in the winter months by the property owner and his family was obtained from the water meter readings. It was assumed that the total amount of water used by the household would eventually go into the septic tank-tile field system. On this basis, the hydraulic loading rate on the tile field was computed by dividing the total volume of septic tank effluent per day by the tile field area which was assumed to be equal to the total length of the tiles multiplied by 0.46 m (1.5 ft.), normally the minimum width of a tile trench.

(vii) The performance of the tile field was studied with regard to the adequacy of the infiltrative capacity of the soil in the tile field. The property owner was interviewed and the information about the usage of the waste disposal system and its year-round performance was obtained. In the field, "quick draw" * tensiometers were used to measure the wetness of the soil above the tiles at

* Available from Soil Moisture Equipment Corp., Santa Barbara, California, U.S.A.

the depth of 0.46 m (1.5 ft.) (the length of the tensiometer). If the soil was very wet or near saturation, the tensiometer would record a near-zero reading; if the soil was quite dry, the tensiometer would indicate a high reading (e.g. 50 centibars). The tensiometers were used at some sites in the initial phase of the field investigation. Later on, it was found more desirable to install copper well points (diameter equal to 1.3 cm, perforated at the bottom) above the tiles to measure the level of the septic tank effluent in the tile trench.

(viii) The depth of the ground water table at each site was determined by measuring the water level in well points installed below the ground water table.

In the soil laboratory, the work done consisted of:

(i) Identification and classification tests performed on disturbed soil samples recovered from borings made at the test site. The laboratory tests were particle size distribution (sieve analysis and hydrometer tests), plasticity, (liquid limit and plastic limit) moisture content and density.

(ii) Hydraulic conductivity (permeability) measurements were done on "undisturbed" block samples obtained from an excavation on the site. The soil was carefully trimmed to a cylindrical shape on a specially designed trimming device (Figure 1). Then the soil sample was put in a plastic split mould and bentonite was used to seal the space between the rigid mould and the soil sample. The junction of the two halves of the mould was sealed by a silicone rubber strip and petroleum jelly. Figure 2 and Figure 3 show the components of the mould and the set up of the hydraulic conductivity test apparatus. The test was performed by the "Falling Head" method. (ASTM, 1970).

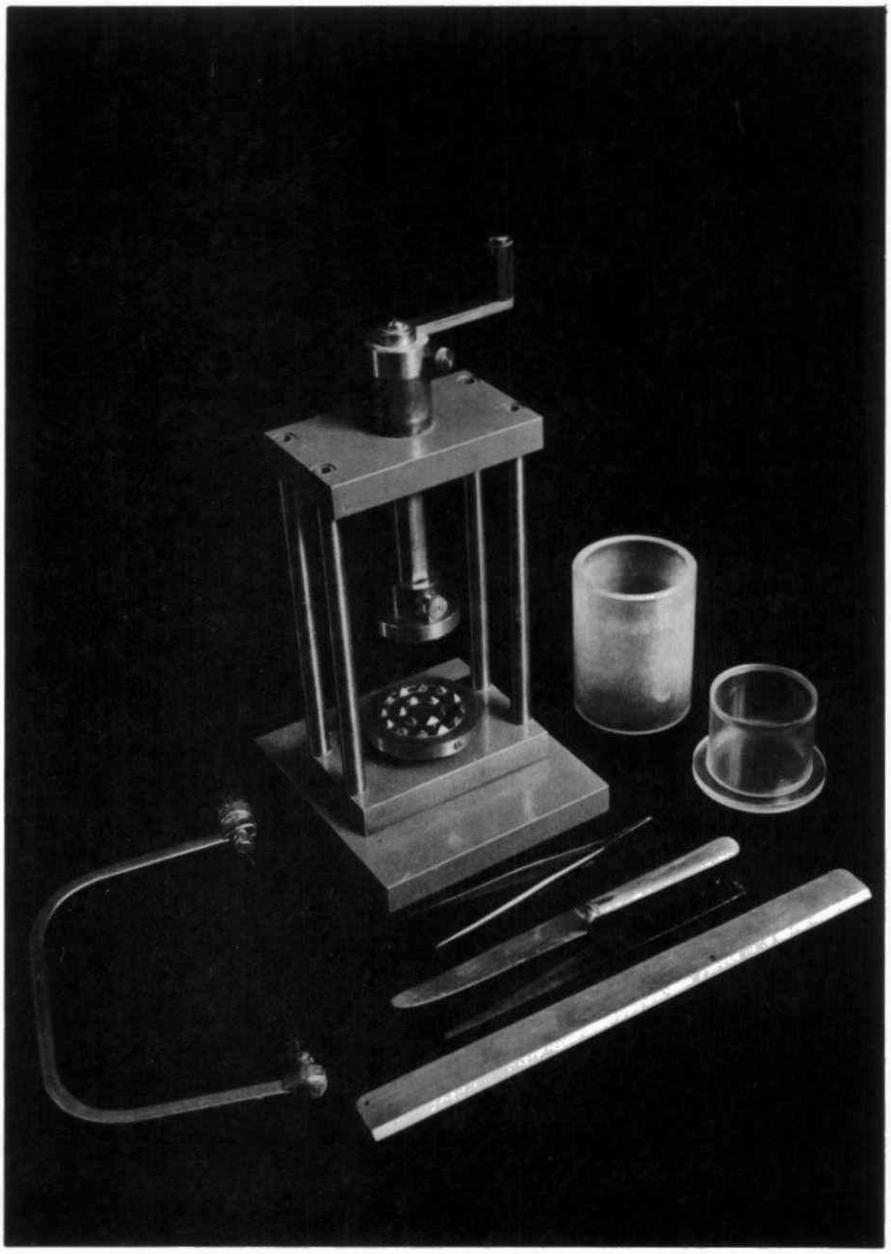

FIGURE 1. TRIMMING DEVICE FOR SOIL SAMPLES

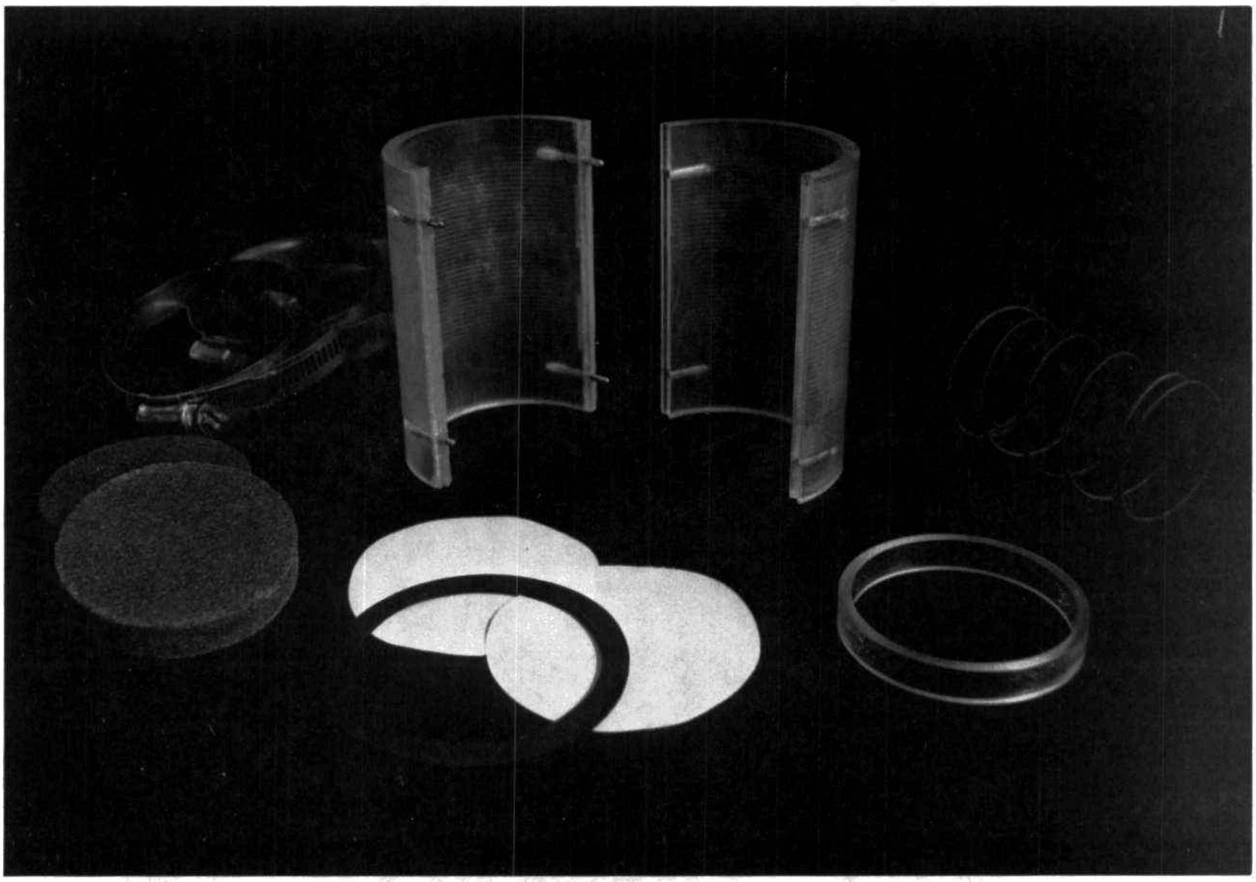

FIGURE 2. COMPONENTS OF THE SPLIT MOULD

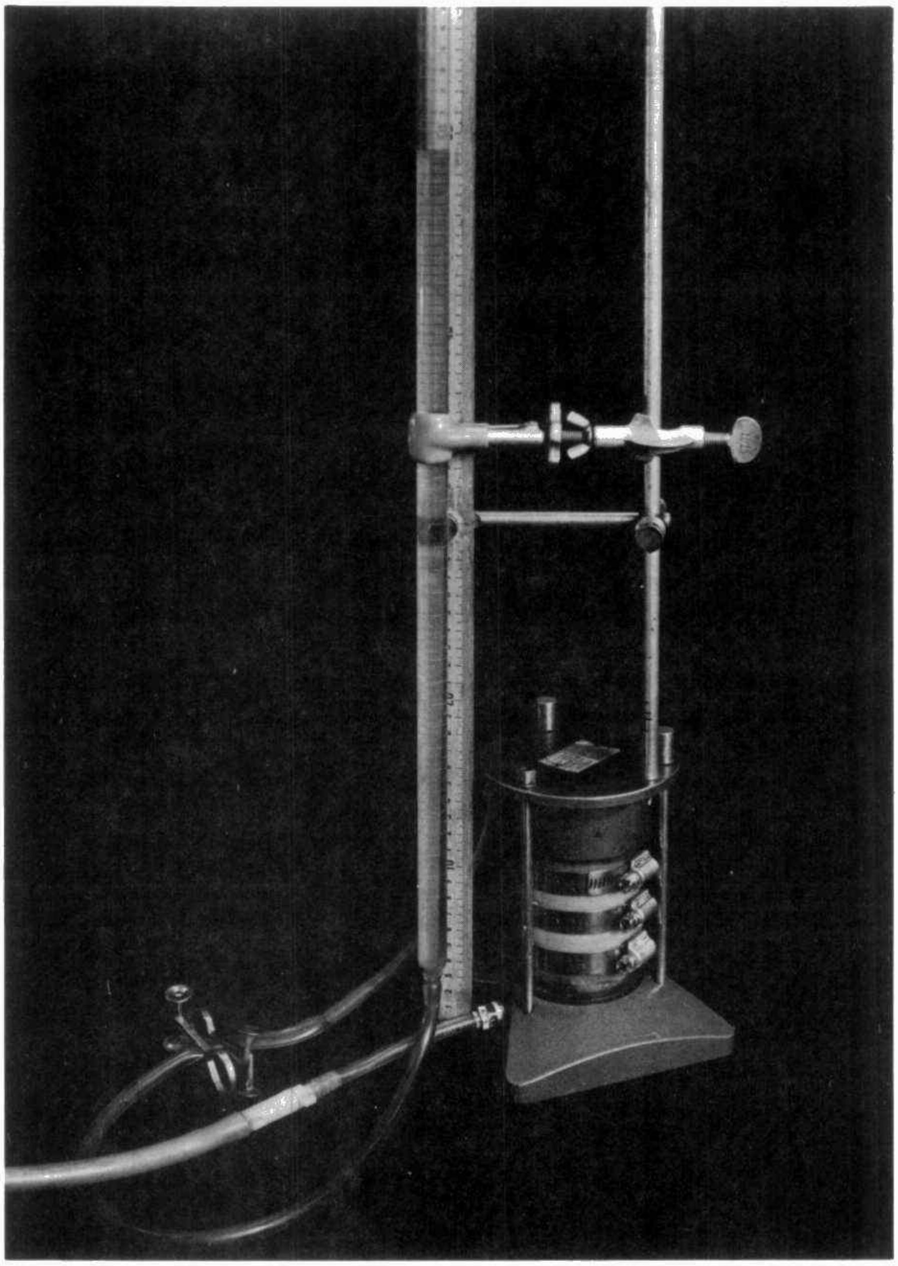

FIGURE 3. SET UP OF APPARATUS FOR HYDRAULIC CONDUCTIVITY TEST

3. FIELD TESTING SITES

Twelve sites were selected for field studies, all located in an area between Toronto and Barrie. A group of six sites was located in a subdivision developed in 1969 and in this report this subdivision is referred to as Area A. Another group of four sites was situated in a subdivision just south of Barrie and this area is referred to as Area B. The remaining two sites will be discussed individually.

3.1 Area A - Six Sites

This subdivision is located in a farming region in Ontario and consists of approximately 100 detached houses. The topography of the area was moderately to steeply sloping. According to the soil survey of Simcoe county (Hoffman et al, 1962), the soils at the site are classified as loam and sandy loam. Except for differences in texture both soils have the same profile characteristics. These soils are considered typical of the Grey-Brown Podzolic Great Soil Group. The profile consists of a very dark greyish brown A_1 horizon about 8 cm (3 in.) thick overlying an A_2 horizon of yellowish brown colour which grades to a slight grey. The dark brown B horizon occurs at a depth of about 0.6 m (2 ft.) and contains more clay than the layers above or below it. This soil rests on light grey calcareous loam or sandy loam till parent material.

The septic tank-tile field systems were approved for construction in 1969 and were built by the same contractor for the residents of the subdivision. The private waste disposal systems had basically the same design. The septic tank was a two-compartment 3637 L (800 gals) pre-cast concrete tank and the total length of the tiles was 122 m (400 ft.). The spacing of the tiles was either 1.2 m (4 ft.) or 1.5 m (5 ft.), but the number of rows of tiles varied from site to site. The depth of the tiles was also different at different sites and sometimes the depth was in excess of the usual 0.5 m to 0.75 m (1.5 ft. to 2.5 ft.) because subsequent to the installation of the systems, some fill was placed by the owners in the tile field areas.

3.1.1 Site A1

The layout of the septic tank-tile field system is presented in Figure 4. A total of four people (2 adults and 2 children) used the system and the hydraulic loading rate on the tile field was 15.7 $L/m^2/d$ (0.32 gals./ $ft.^2$/day). The depth of the tiles was approximately 0.9 m (3 ft.) below the ground surface. The topography of the site is illustrated by the contour lines in Figure 4, which indicate that the surface drainage is in the northerly direction..

A number of borings were made on the site to determine the soil stratigraphy and to obtain soil samples for laboratory tests. It was found that below the top soil (approximately 0.1 m thick) there was a layer of clayey silt extending to the depth of 0.9 m (3 ft.). This soil consisted of about 28% sand, 54% silt and 18% clay. From the depth of 0.9 m (3 ft.) downward, a sandy silt layer was encountered and this soil was very slightly plastic (58% sand, 36% silt and only 6% clay). The soil stratigraphy was verified by an excavation on the west side of the tile field to the depth of about 1.2 m (4 ft.).

A total of five percolation holes were dug in or near the tile field area (Holes 1 to 5 as shown in Figure 4) and six tests were done in the spring season of 1976. Test results are presented in Table 1, which indicate that the percolation time of the soil was not greater than 24 min/cm (60 min/in.). Also, the percolation time at the depth of 0.9 m (3 ft.) was larger than that at the depth of 0.6 m (2 ft.). This was probably because the soil at the shallower depth had more hair-line cracks and fissures as a result of weathering or worm holes.

Tensiometers were used to measure the wetness of the soil in the tile field area in May and June of 1976. It was found that in May 1976, the average tensiometer reading in the soil above the tiles was 26 centibars * and the average reading in the soil in the vicinity of the tile field was 38 centibars.

* 1 Bar = 100 centibars = 100 Kpa = 14.5 $lbs./in.^2$

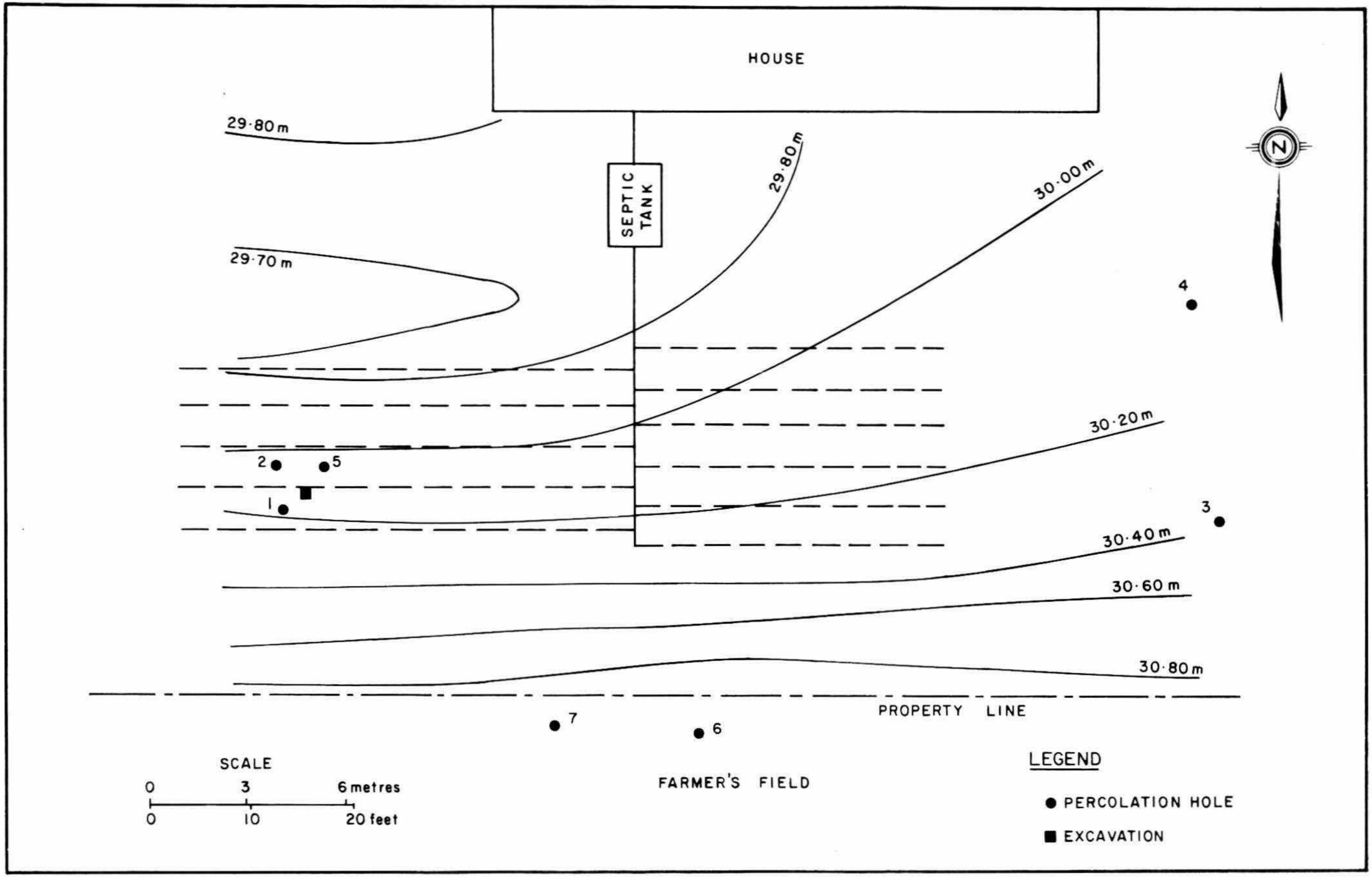

FIGURE 4 : LAYOUT, TOPOGRAPHY AND LOCATIONS OF PERCOLATION HOLES AT SITE A1.

TABLE 1 SUMMARY OF PERCOLATION TEST RESULTS (AREA A)

SITE	HOLE	DEPTH (m)	DEPTH (ft)	PERCOLATION TIME (min/cm)	PERCOLATION TIME (min/in)
A1	1	0.6	2.0	21	53
	2	0.6	2.0	16	40
		0.9	3.0	23	59
	3	0.6	2.0	6	15
	4	0.6	2.0	12	30
	5	0.9	3.0	20	52
	6	0.9	3.0	9	22
	7	0.9	3.0	50	127
A2	1	0.8	2.5	142	360
		1.2	4.0	46	116
	2	0.8	2.5	117	296
		1.2	4.0	48	122
	3	1.2	4.0	43	110
	4	1.2	4.0	37	94
	5	0.9	3.0	38	96
	6	0.9	3.0	47	119
	7	0.9	3.0	15	38
A3	1	0.8	2.5	114	290
	2	0.8	2.7	15	39
	3	0.8	2.5	46	117
	4	0.8	2.5	51	130
	5	0.9	2.8	59	150
	6	0.8	2.5	4	9
	7	0.9	3.0	164	416

.....continued

TABLE 1 (Cont'd)

SITE	HOLE	DEPTH (m)	DEPTH (ft)	PERCOLATION TIME (min/cm)	PERCOLATION TIME (min/in)
A4	1	1.0	3.2		*
	1A	1.2	3.8	202	512
	2	0.7	2.2	125	317
	2A	0.6	2.1	71	180
	3	0.6	2.0		*
	4	0.6	2.0		*
	5	0.6	2.0	45	115
	6	0.6	2.0	189	480
A5	1	0.9	3.0	148	375
	2	0.9	3.0	277	704
	3	0.9	3.0	253	896
	4	0.9	3.0	95	242
A6	1	0.8	2.5	1	2
	2	0.7	2.3	10	26
	3	0.7	2.3		*
	4	0.8	2.5		*
PARK (Location 1)					
	1	0.6	2.0	9	23
	2	0.7	2.3	6	16
	3	0.6	2.0	6	15
	4	0.7	2.3	5	12
PARK (Location 2)					
	1	0.9	3.0	19	47
	2	0.8	2.5	22	55
	3	0.6	2.0	3	8
	4	0.6	2.0	3	8

* Practically no movement in the water level in several hours during the test. Percolation time assumed > 400 min/cm (1000 min/in).

In June, it was found that the average tensiometer readings were equal to 33 centibars in the soil above the tiles and in the vicinity of the tile field. It can be concluded that at these times of investigation, the soil above the tile trenches was quite dry.

In 1977 (May to October), small copper well points were installed above the tile trenches to measure the water level. Measurements were taken approximately once a month and at all times, no water was detected in the well points. Therefore, it can be concluded that, at least at the time of investigation, no ponding of septic tank effluent occurred in the tile trenches.

During many visits to the site in different seasons in 1976 and 1977, the ground surface of the tile field was visually examined for signs of surface ponding. It was found that the system was quite satisfactory.

The location of the water table was determined by installing two well points at the site. The water table was found to be more than 1.6 m (5 ft.) below the ground surface.

It was not possible to take an "undisturbed" block soil sample from the sandy silt layer for the measurement of the hydraulic conductivity (permeability) in the laboratory. Instead, a disturbed sample was recovered and a soil sample was compacted in the laboratory for the test, which gave the result of 9.4×10^{-4} cm/s at the dry density of 1.8 g/cm^3 (114 lbs./ft.^{3}).

In the summer of 1977, two additional percolation tests were done on the southside of the fence line (Holes 6 and 7 as shown in Figure 4). The purpose of this investigation was to determine the variability of the drainage characteristics of the soil within a small area at the test site. The subsoil stratigraphy on the southside of the fence line was quite different from what was found in the tile field area. At the locations of the percolation holes 6 and 7, the subsoil consisted of a few cm of top soil underlain by a powdery sandy silt which was similar to the soil found at the depth of 1.2 m (4 ft.) in the tile field area. In holes 6 and 7, the soil conditions were similar; however, the percolation time was quite different (see Table 1).

In summary, it can be concluded that the soil in the tile field had adequate absorptive capacity for the septic tank effluent. The main factors contributing to this operational success were: (i) favourable soil drainage characteristics (percolation time less than 24 min./cm), (ii) low hydraulic loading rate (15.7 L/m^2/d), and (iii) good surface drainage condition (i.e. surface water drainage away from the tile field area).

3.1.2 Site A2

Figure 5 shows the general topography of the site and the approximate location of the tile field, which was located on the flat area behind the house. The slope behind the backyard was quite steep and it was the result of grading during the development of the subdivision and subsequent filling of the backyard by one of the house owners. It was reported that about 0.6 m (2 ft.) of soil was placed on the ground surface after the tile field system was constructed. Because the tiles were quite deep and the soil was hard, it was not possible to locate exactly the tiles in the ground. The location of the tile field was determined on the basis of information from the local health unit and the present home owner. However, the location of the septic tank was found near the house and is shown in Figure 5. The depth of the tiles was probably 1.2 m (4 ft.), judging from the thickness of the fill which was placed on the ground surface after the construction of the system.

There were four people (2 adults and 2 children) using the septic tank-tile field system and the average hydraulic loading rate on the tile field was 11.0 L/m^2/d (0.22 gals./ft.^{2}/day).

Soil borings revealed that the subsoil was a clayey soil with 25% to 31% clay, 49% to 55% silt and 13% to 25% sand, and the liquid limit and plastic limit was 37 and 20 respectively.

A total of nine percolation tests were performed in the area adjacent to the tile field. In some holes, tests were done at two depths to determine the percolation time of the soil at two levels. Table 1 summarizes the test results. The depth of the water table at the site was greater than 1.5 m (5 ft.) as measured in the well points. Block samples were recovered from two

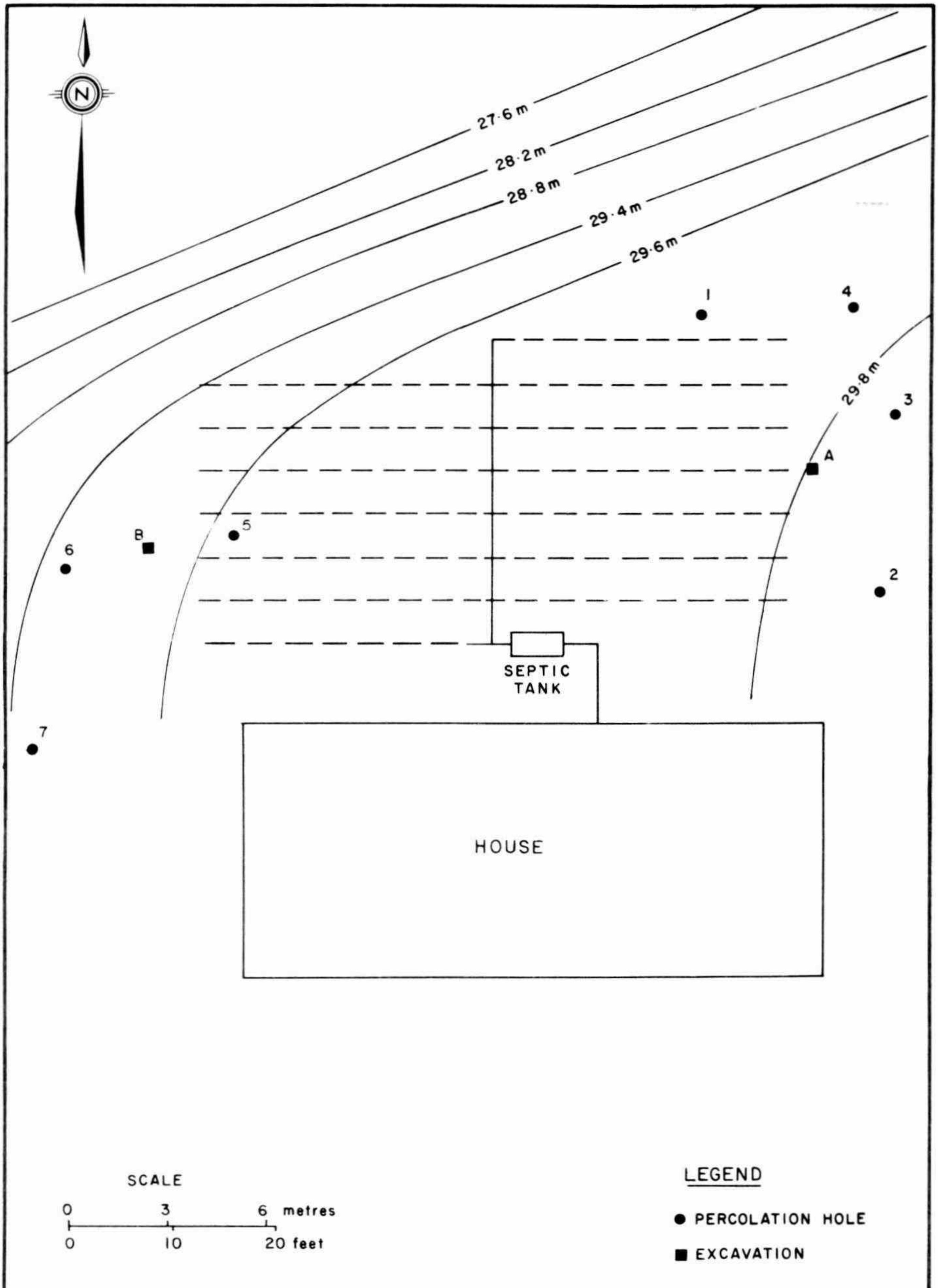

FIGURE 5 : LAYOUT, TOPOGRAPHY AND LOCATIONS OF PERCOLATION HOLES AT SITE A2

excavation holes (A and B as shown in Figure 1) for the measurement of the hydraulic conductivity in the laboratory. The test results are contained in Table 2.

During many visits to the site in different seasons in 1976 and 1977, the ground area above and adjacent to the tile field was visually examined for signs of surface ponding of septic-tank effluent. From the information provided by the house owner and the observations made in the field, the tile field appeared to have experienced no difficulties in the sorption of the septic tank effluent at different times of the year.

The tile field system at this site functioned quite satisfactorily even though the tiles were located at about 1.2 m below the ground surface. Several factors could account for the successful operation of the system. The average percolation time at the depth of 1.2 m was about 43 min./cm (110 min./in.) and the laboratory hydraulic conductivity was in the order of 5×10^{-5} cm/s. The soil was not very permeable; however, it was apparently adequate for the low applied hydraulic loading rate (11.0 $L/m^2/d$). The surface drainage was reasonably good because of the topography in the tile field area and, the water table was greater than 1.5 m (5 ft.).

It is of practical interest to note that the performance of the tile field was satisfactory even though the percolation time of the soil exceeded 24 min./cm (60 min./in.). Furthermore, it was found that the soil at the shallower depth had a larger percolation time than the similar soil at greater depth. This may be explained by the fact that the soil at the shallower depth was a fill material and was disturbed and remoulded by compaction.

3.1.3 Site A3

The topography of the backyard where the tile field was located was sloping away from the house. Figure 6 shows the contour lines of the area around the tile field and also the locations of the tiles. The depth of the water table in the summer of 1977 was approximately 1.5 m (5 ft.) below the ground surface. The six rows of tiles were located at the depth of approximately

TABLE 2 RESULTS OF LABORATORY HYDRAULIC CONDUCTIVITY MEASUREMENTS (AREA A)

SITE	SAMPLE DEPTH (m)	(Ft)	DRY DENSITY (g/cm^3)	MOISTURE (%)	HYDRAULIC CONDUCTIVITY (cm/s)
A2	1.1	3.5	1.59	20.0	2.9×10^{-4}
	1.1	3.5	1.65	22.3	4.0×10^{-5}
	1.2	4.0	1.57	16.0	6.1×10^{-5}
A3	0.8	2.5	1.49	22.8	2.0×10^{-5}
	0.9	3.0	1.70	21.5	5.5×10^{-8}
A4	0.8	2.5	1.63	21.5	1.0×10^{-5}
	1.2	4.0	1.63	17.5	3.7×10^{-5}
A6	0.76	2.5	1.59	21.3	2.6×10^{-4}
	0.91	3.0	1.61	25.8	7.7×10^{-8}

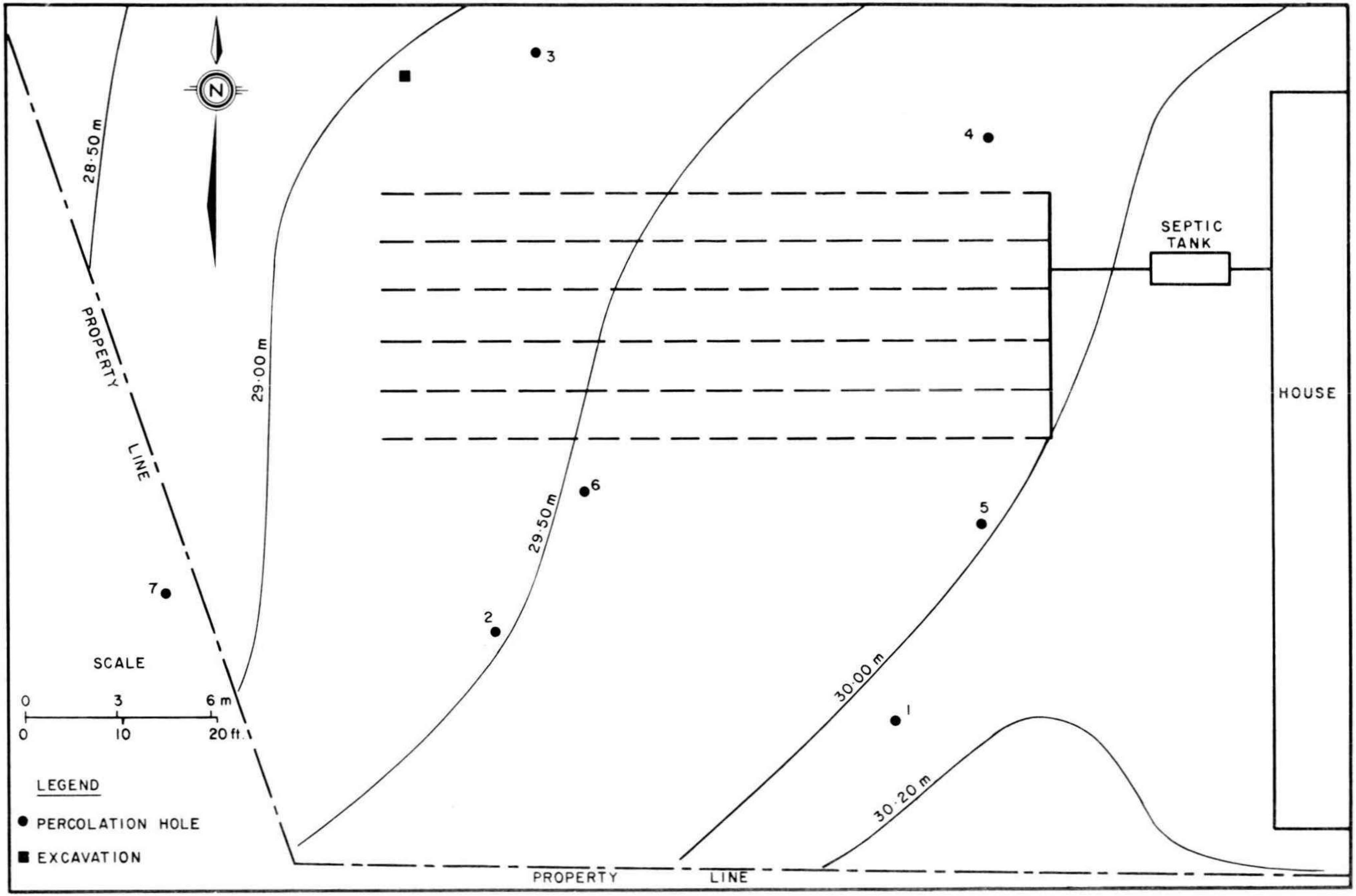

FIGURE 6: LAYOUT, TOPOGRAPHY AND LOCATIONS OF PERCOLATION HOLES AT SITE A3.

0.76 m (2.5 ft.). There were five people using the disposal system at the time of the field investigation and the hydraulic loading rate on the tile field was about 16.6 $L/m^2/d$ (0.34 gals./$ft.^2$/day).

A total of nine borings were made in and adjacent to the tile field area with a small hand auger (3 cm in diameter). Soil samples were taken up to the depth of 1.8 m (6 ft.) for visual examinations and laboratory tests. It was found that there was about 5 to 7 cm of top soil underlain by clayey silt; some organic material was found in the soil at the shallow depth down to 0.6-0.9 m . The colour of the soil changed from mottled brown to grey with increasing depth. The clayey silt consisted of about 5% sand, 59 to 69% silt and 27 to 36% clay; the liquid limit was from 41 and the plastic limit was 21.

The wetness of the soil above the tiles was determined with tensiometers. At the depth of 45 cm (18 in.) and in nine locations above the tiles, the tensiometer readings ranged from 40 to 70 centibars. When these tensiometer readings were obtained on September 1, 1976, there had been rain for a few days; thus, the tensiometer readings indicated that the soil above the tiles was quite dry even after a few rainy days. In the summer and fall seasons of 1976 and in the spring time of 1977 the wetness of the soil above the tiles was visually examined. No ponding of effluent on the ground surface was noticed at any time.

A total of six percolation tests were done around the tile field to measure the percolation time of the soil. Also, a test was done outside the property to compare soil conditions (Figure 6). Table 1 summarizes the test results.

Two "undisturbed" block soil samples were taken in an excavation near the tile field at the depths of 0.76 m (2.5 ft.) and 0.91 m (3 ft.). These block samples were returned to the laboratory for the measurement of the hydraulic conductivity. The test results are summarized in Table 2.

The tile field system on the lot functioned satisfactorily and at the time of the field investigation no sign of ponding of the septic tank effluent was ever observed. Several factors could be responsible for the

successful operation of the system.

(i) The surface drainage condition was good--the surface water was draining from the tile field area to the far end of the property line as shown by the contour lines in Figure 6.

(ii) The soil at the depth of 0.8 m (2.5 ft.) indicated a relatively good permeability for the clayey soil (2×10^{-5} cm/s) which contained a fair amount of organic matter. However, the soil at 0.9 m (3 ft.), which was a more compact brown clayey silt was much less permeable (5.5×10^{-8} cm/s). It is believed that the more permeable soil at the shallower depth would play a major role in the adsorption of the septic tank effluent.

(iii) There were six percolation tests done at this site and holes 3 to 6 were located on both sides of the tile field. Holes 3, 4, and 5 gave a percolation time in excess of 40 min./cm (100 min./in.); however, hole 6 had a much smaller percolation time (i.e. 4 min./cm). The percolation data (Table 1) indicate a large variation of the drainage characteristics of the soil in and adjacent to the tile field. Because of the low loading rate (16.6 $L/m^2/d$) over the tile field area, the average infiltrative capacity of the soil was sufficient to absorb the septic tank effluent.

3.1.4 Site A4

The backyard where the tile field was constructed was bordered by backyards on each side with the third side being a farmer's field. The tile field was situated in the flat area of the backyard with a relatively steep slope on the southside (Figure 7). The tiles were located approximately 0.5 m (19 in.) below the ground surface. The tile-field system served two adults and three children and the hydraulic loading rate on the system was 13.7 $L/m^2/d$ (0.28 gal./ft.^{2}/day).

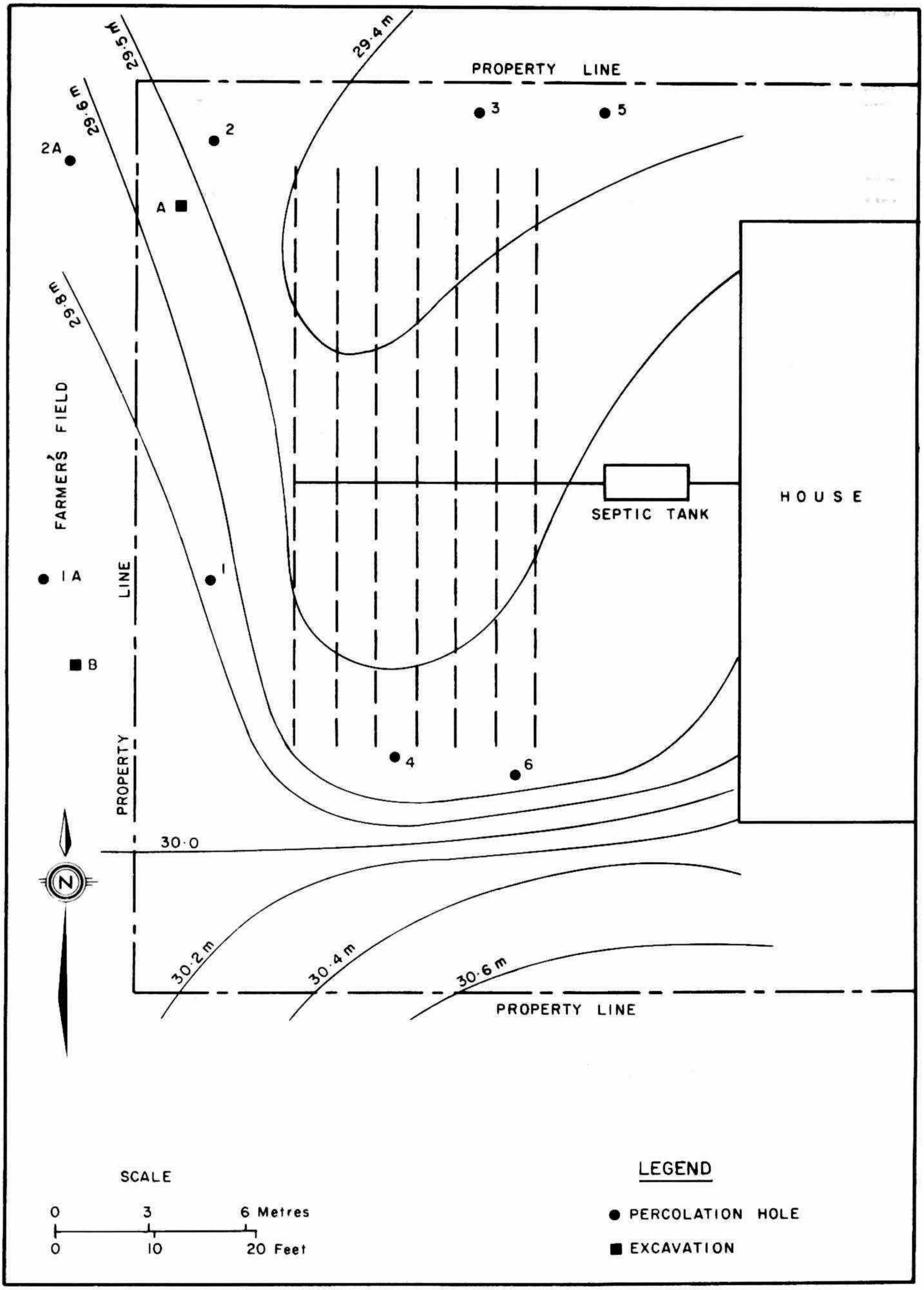

FIGURE 7: LAYOUT, TOPOGRAPHY AND LOCATIONS OF PERCOLATION HOLES AT SITE A4.

The subsoil consisted of 38% to 46% clay, 48% to 51% silt and 6% to 11% sand. The soil was classified as a clay of low plasticity with liquid limit equal to 33, plastic limit equal to 18 and the plasticity index equal to 15.

A total of 8 percolation tests were performed. Six of the percolation holes were dug adjacent to the tile field and two holes (1A and 2A) were made in the farmer's field. Table 1 summarizes the test results, which varied enormously and indicated a large variability of the drainage characteristics of the soils. Two block soil samples were obtained in two excavations (A and B as indicated in Figure 7) and hydraulic conductivity tests were performed on these samples. Test results are contained in Table 2.

According to field observations in April 1977, the ground surface in the tile field area was extremely wet indicating signs of ponding of septic tank effluent in the tile trenches. The grass above the trenches showed very rich, green colour and there was smell of septic effluent. In May 1977, small copper well points were installed above the tiles and the water level measurements indicated that the level of the effluent was only about 30 cm (12 in) below the ground surface. In June 1977, the effluent level in the trenches dropped to 38 cm (15 in) below the ground surface and in the summer season, the tile trenches were practically dry.

The water table vaired from 0.9 m to 1.5 m (3 ft to 5 ft) according to piezometers installed on the property.

According to the on-site observations regarding the performance of the tile field, it can be concluded that the system failed during the wet seasons of the year even though the hydraulic loading rate on the tile field was low. The main factor for the failure was the relatively impermeable soil conditions, coupled with poor surface drainage. On the southside of the tile field the ground surface was about 1 m higher than the tile field area. During the spring season, the surface runoff would be flowing from the high

ground to the flat area, where the tile field was located. In the summer season, the tile field would work satisfactorily with the help of evapotranspiration under the warm climatic conditions.

Referring to Table 2, the average laboratory hydraulic conductivity of the soil was 2.4×10^{-5} cm/s, which is relatively good for a clayey soil. However, it is believed that in most areas adjacent to the tile field, the soil conditions would not be as favourable as indicated by the two laboratory hydraulic conductivity tests. The big difference in the percolation test results would support the non-homogeneous drainage characteristics of the subsoil.

3.1.5 Site A5

The layout of the tile field and the ground surface contour lines are shown in Figure 8. The depth of the tiles was approximately 1 m (3.3 ft) below the ground surface. As shown in Figure 8, the tile field was located in the relatively flat area of the lot and this area was the lowest part on the property. The well points indicated that the water table outside the tile field varied at different times of the year. From June to October 1977, the ground water table fluctuated from 0.3 m to 1 m below the ground surface at Point A1, and the variations at point A2 were 0.5 m to 0.7 m, at point A3 0.1 m to 0.7 m, and at point A4 0.4 m to 1.7 m. There were three people (1 adult and 2 children) using the system and the hydraulic loading rate on the tile field was approximately equal to 10.0 $L/m^2/d$ (0.20 $gals./ft.^2/day$).

The site was underlain by a few cm of top soil overlying a layer of brownish-grey clayey silt material. The soil consisted of 37% to 46% clay, 54% to 61% silt and it was classified as a clay of low plasticity (liquid limit = 34, plastic limit = 19 and plasticity index = 15).

A total of four percolation tests were performed on the site. The locations of the percolation holes and the time of performing the tests were controlled by the depth of the water table. The percolation holes were 0.9 m (3 ft.) deep and the percolation test results are summarized in Table 1.

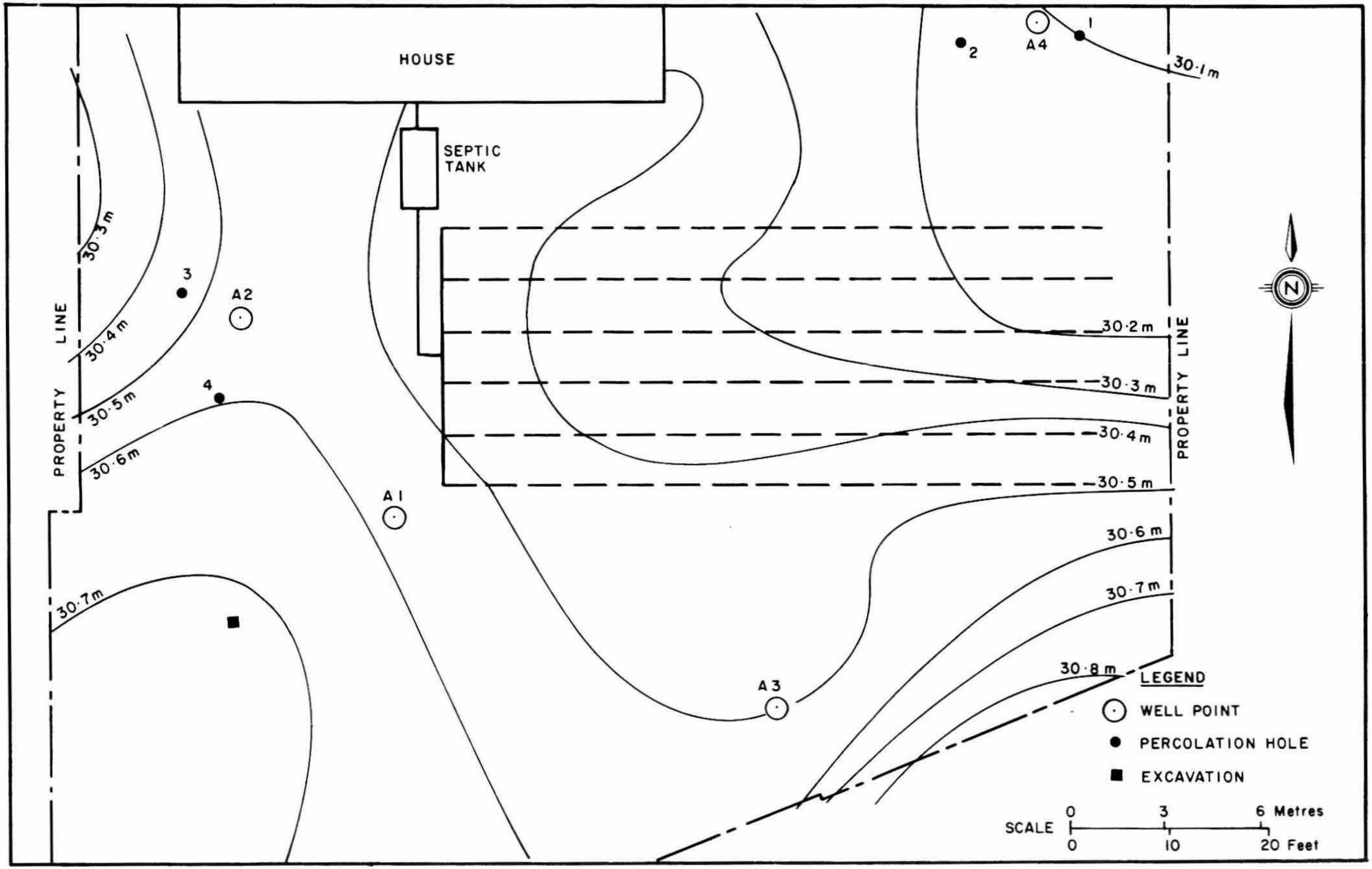

FIGURE 8: LAYOUT, TOPOGRAPHY AND LOCATIONS OF PERCOLATION HOLES AND WELL POINTS AT SITE A5.

A number of short copper pipe well points were installed above the tile trenches. Measurements of the water levels in these pipes were taken approximately once a month from May 1977 to October 1977. In May to July, the water level in the tile trenches was not greater than 0.2 m below the ground surface. In August to October, the water level was at the ground surface, i.e. the septic tank effluent was ponded on the ground surface. In the spring time in 1977, it was observed that the ground surface in the tile field area was very wet and soggy.

A block soil samples was taken from an excavation 1 m deep for laboratory hydraulic conductivity measurements. The laboratory test showed that the hydraulic conductivity of the soil was equal to 0.5×10^{-5} cm/s (dry density = 1.54 g/cm^3 (96.4 $lbs/ft.^3$)).

From the field observations, the tile field system did not function satisfactorily. Most of the time, the ground surface in the tile field area was wet and soggy indicating a severe surface ponding of septic tank effluent. The failure of the tile field was attributed to two main factors: (i) unfavourable soil conditions. (i.e. large percolation time and high percentage of clay in the soil); and (ii) poor surface drainage (i.e. water adjacent to the tile field was collected in the flat area where the tile field was constructed). As a result of the poor surface drainage at the site, the water table in the vicinity of the tile field was quite high, which would interfere with the flow of water from the tiles to the ground water system.

3.1.6 Site A6

The site was bordered by neighbour's backyard and a park. The topography of the backyard where the tile field system was located was not surveyed because it was not possible to get the property owner's permission. Generally, the backyard was sloping gently from the house towards a small turtle pond. The tile field was located between the house and the pond (Figure 9). As shown on the drawing, there was a tile extending out from the tile field. This extra line of tile was installed by the present house

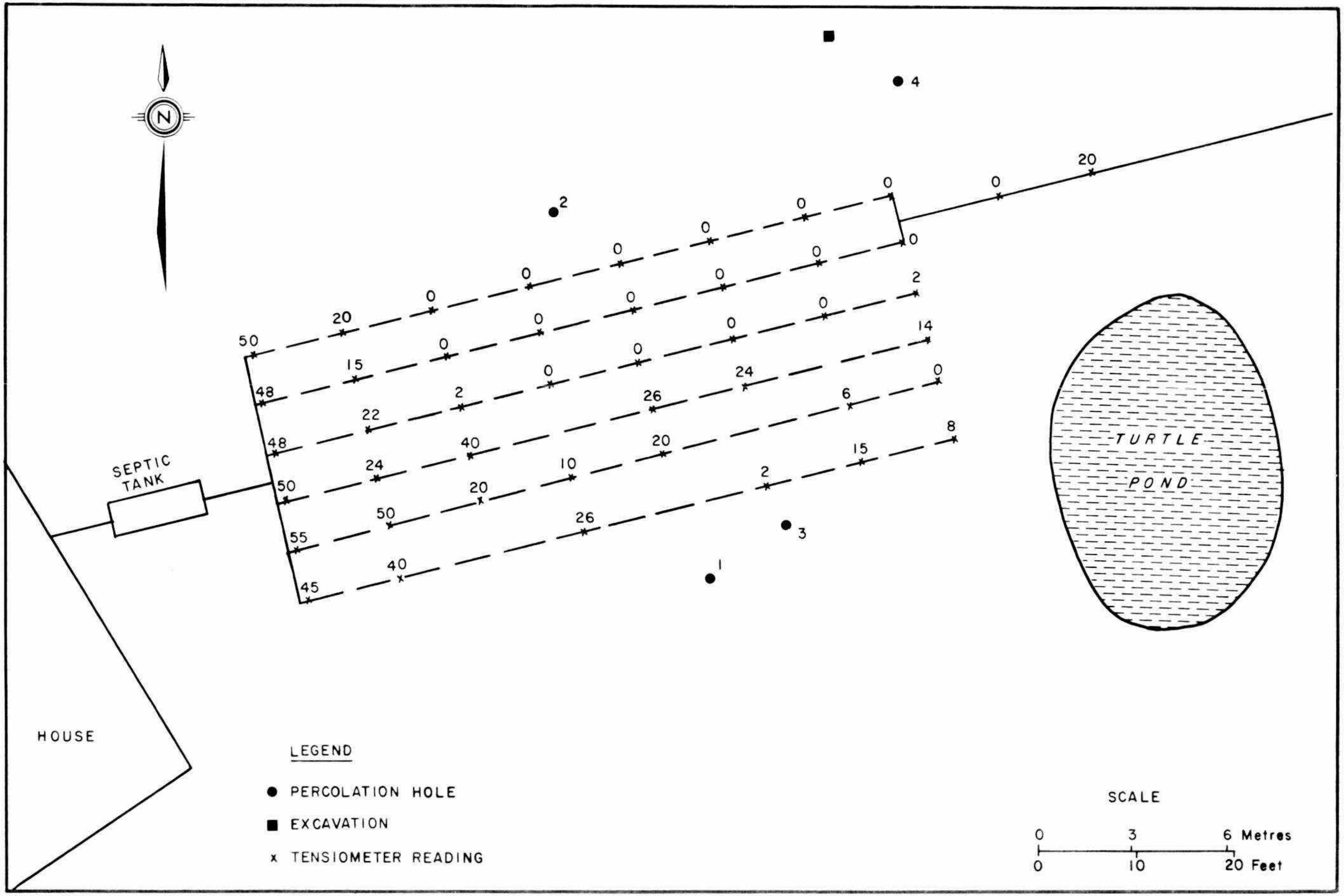

FIGURE 9: LAYOUT, LOCATIONS OF PERCOLATION HOLES AND TENSIOMETER TEST READINGS AT SITE A6.

owner because he noticed that the ground surface above the two lines of tiles on the northside of the tile field was frequently wet (i.e. sign of ponding). According to the house owner, the additional line of tiles appeared to have alleviated the problem.

There were four people using the tile field system and the average hydraulic loading rate was 17.6 $L/m^2/d$ (0.36 gals./ft.^{2}/day).

Soil borings and laboratory tests revealed that the subsoil consisted of 24 to 35% clay, 61 to 64% silt and a trace of sand. The soil was classified as a clay of intermediate plasticity (Liquid limit = 39, plastic limit = 20 and plasticity index = 19).

Four percolation tests were performed and the results are summarized in Table 1. The percolation time varied enormously indicating the heterogeneous nature of the subsoil at the site.

The wetness of the soil above the tile trenches was studied with tensiometers in August 1976. The measurements are summarized in Figure 9. The wet area experienced by the house owner generally coincided with the area of zero tensiometer readings.

According to the house owner, the tile field appeared to be functioning satisfactorily. During field visits to the site, it was observed that the ground surface above the tiles was reasonably dry, with the exception that in late March 1977, the north portion of the tile field was wet on the ground surface. Block soil samples were taken from an excavation for the hydraulic conductivity tests. In the excavation, it was found that there was a thin layer of top soil with dead grass at the depth of 0.6 m (2 ft.), which indicated that the soil above 0.6 m was probably a fill material. Below the top soil layer at the depth of 0.6 m, there was about 0.3 m of clayey silt with some organic material, which was underlain by a very dense clayey silt soil. The hydraulic conductivity results are summarized in Table 2.

From the results of the tensiometer readings obtained in August 1976 and the observations made at the site on several occasions, it can be concluded that the system experienced some difficulties in absorbing the septic

tank effluent. The partial operational problem of the tile field could be attributed to the existence of the very compact clayey silt soil located at the depth of about 0.9 m. The percolation test results also indicated the poor drainage characteristics of the soil in some areas in the tile field. Furthermore, the investigations suggested that the distribution of the septic tank effluent in the tile field was not uniform. (i.e. a larger portion of the effluent was flowing into the north portion of the tile field).

3.1.7 Percolation Tests in a Park

A number of percolation tests were performed in a park on the northside of site A6 and the results are summarized in Table 1. The soils (clayey silt) in the park are similar to those found in the six test sites (A1 to A6). The purpose of conducting these tests was to assess the variations of the percolation time ("t" time) of soils within the subdivision (i.e. Area A).

3.2 Area B - Four Sites

This subdivision was developed in 1971 and consisted of about 200 single houses. The subdivision was sloping at about 1.7% from the northwest corner to the southeast corner. The soil conditions in the area were similar to those in Area A.

The design for the septic tank systems constructed in the natural soils was similar. The liquid capacity of the septic tank was 3864 L(850 gal.) and the total length of the tiles was 122 m (400 ft.) for most systems. However, the spacing and the depth of the tiles varied at different sites.

3.2.1 Site B1

The layout of the tile field and ground surface contour lines are shown in Figure 10. The depth of the tiles was approximately 0.7 m (2.2 ft.) below the ground surface, which was relatively flat with surface drainage in the east and west direction. The well points installed on the site indicated that the water table was more than 1.1 m (3.8 ft.) below the ground surface during July to November 1977. The small copper well points installed above

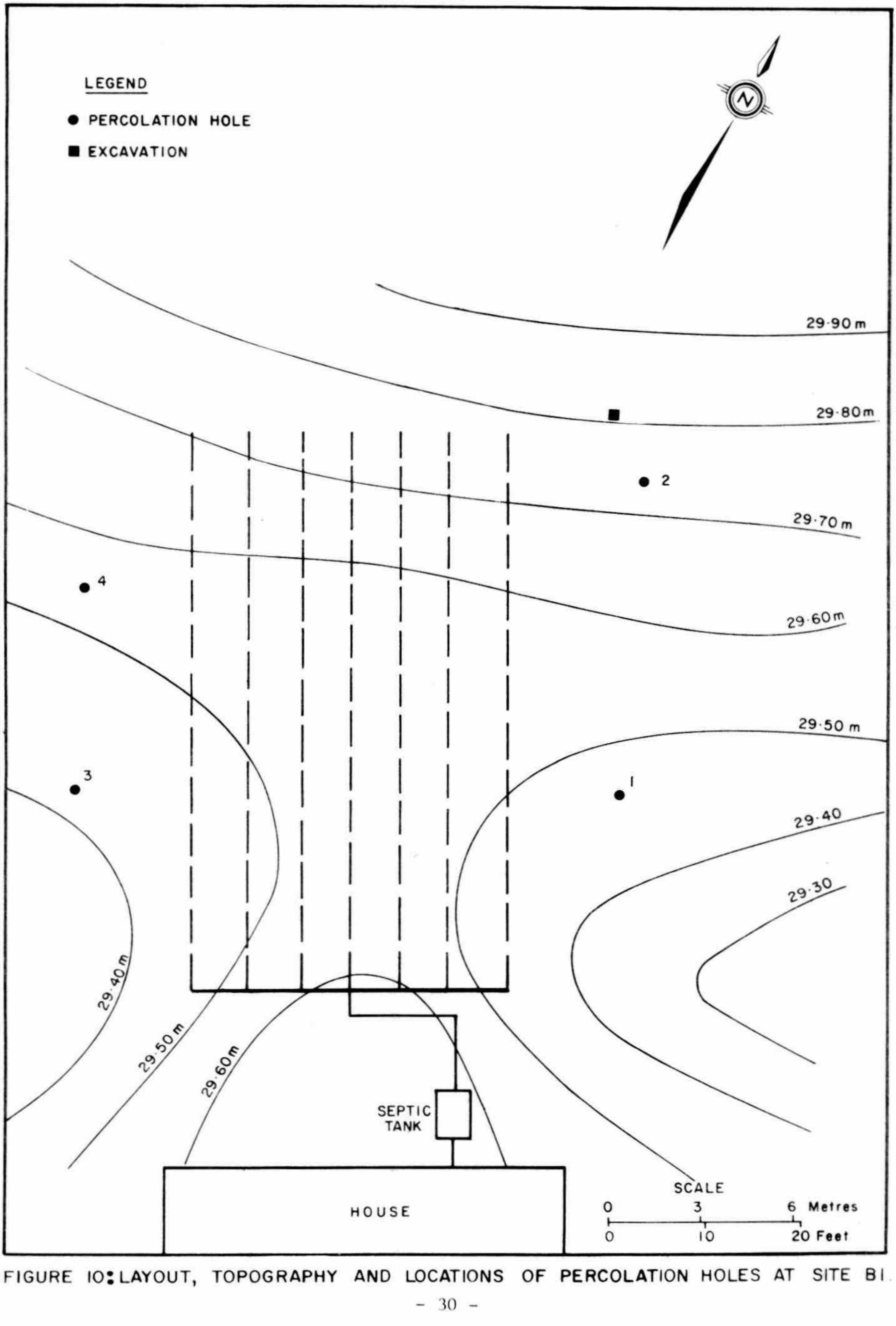

FIGURE 10: LAYOUT, TOPOGRAPHY AND LOCATIONS OF PERCOLATION HOLES AT SITE B1.

the tile trenches were dry during the monitoring period (July to November 1977), indicating the soil had sufficient absorptive capacity for the septic tank effluent at the time of field study.

There were four people using the system (2 adults and 2 children) and the hydraulic loading rate on the tile field was equal to 11.65 $L/m^2/d$ (0.24 $gals./ft.^2/day$).

The site was underlained by a few cm of top soil overlying a layer of brownish grey clayey silt material. This soil consisted of 27 to 31% sand, 35 to 52% silt and 20 to 34% clay (liquid limit = 40, plastic limit = 20). A total of four percolation tests were done on the site and the test results are summarized in Table 3. Several block soil samples were obtained from an excavation and, subsequently, two hydraulic conductivity measurements were determined. Test results are contained in Table 4.

From the measurements of the water level in the copper pipes installed in the tile trenches, it can be concluded that at the time of the investigation the performance of the tile field was quite satisfactory. The successful operation of the system probably can be attributed to two main factors:

(i) the low hydraulic loading rate on the system (11.65 $L/m^2/d$) and,

(ii) part of the tile field was installed in soil with a percolation time of about 24 min./cm (60 min./in). The percolation test results from the site indicated that the soil on the westside of the tile field was much more permeable than the soil on the eastside. If it could be assumed that 50% of the tile field was constructed in the "better" soil (i.e. percolation time approximately 24 min./cm) and all the effluent from the septic tank were discharged into this part of the tile field, the absorptive capacity of the soil would still be adequate to accommodate twice the hydraulic loading rate of (23.3 $L/m^2/d$ (0.48 $gals./ft.^2/day$)).

TABLE 3 SUMMARY OF PERCOLATION TEST RESULTS (AREA B)

SITE	HOLE	DEPTH (m)	DEPTH (ft)	PERCOLATION TIME (min/cm)	PERCOLATION TIME (min/in)
B1	1	0.9	3.0	113	288
	2	0.9	3.0	121	308
	3	0.9	3.0	30	75
	4	0.9	3.0	20	50
B2	1	0.6	2.0	38	97
	2	0.6	2.0	84	213
	3	0.6	2.0	226	573
	4	0.6	2.0	1	2
B3	1	0.8	2.5		*
	2	0.8	2.5	98	248
	3	0.8	2.5		*
	4	0.8	2.5	17	43
B4	1	0.6	2.0	384	976
	2	0.6	2.0	362	920
	3	0.6	2.0	37	94

* Practically no movement in the water level in several hours during the test. Percolation time assumed > 400 min/cm (1000 min/in).

TABLE 4 RESULTS OF LABORATORY HYDRAULIC CONDUCTIVITY MEASUREMENTS (AREA B)

SITE	DRY DENSITY (g/cm^3)	MOISTURE (%)	HYDRAULIC CONDUCTIVITY (cm/s)
B1	1.52	18.0	4.8×10^{-5}
	1.60	21.4	7.4×10^{-5}
B2	1.57	18.3	2.1×10^{-6}
	1.68	15.6	5.0×10^{-5}
B3	1.76	18.1	5.1×10^{-7}
	1.83	14.7	2.1×10^{-7}
B4	1.27	34.7	4.5×10^{-4}
	1.29	34.1	1.1×10^{-4}

NOTE: All soil samples were obtained at the depth of 0.8 m (2.5 ft).

3.2.2 Site B2

Figure 11 shows the ground surface contour lines of the site where the tile field was located. There were seven rows of tiles located at the depth of about 0.6 m (2 ft.). On the southside of the tile field the area was heavily treed. The waste disposal system was used by four people (2 adults and 2 children) and the hydraulic loading rate on the tile field was 10.5 $L/m^2/d$ (0.22 $gals./ft.^2/day$). The tile field was constructed in soil classified as clay of low to intermediate plasticity and consisted of 25 to 30% clay, 36 to 39% silt and 34 to 36% sand. The liquid limit of the soil was 38 and the plastic limit was 17. Two hydraulic conductivity measurements were done on the block soil samples taken from an excavation near the end of the tile field. Test results are summarized in Table 4. Four percolation tests were done on the north and south sides of the tile field and the results (Table 3) indicated a very significant difference in the drainage characteristics of the soils. The water table was about 1.5 m below the ground surface.

Two small well points were installed in each tile trench to monitor the water level from July to November 1977. In August and September 1977, the water level in some of the well points was about 0.4 m (15 in.) below the ground surface, suggesting that some trenches were partially filled with septic tank effluent. However, observations made on the ground surface in the tile field area indicated that the system was operating satisfactorily. According to the owner of the house, the waste disposal system did not have any operational difficulties.

The laboratory results of hydraulic conductivity and the percolation test results obtained in test holes 2 and 3 indicated that the soil at the site was not too permeable. However, the test data from percolation holes 1 and 4 suggested much more favourable soil conditions. The percolation time in hole 4 was extremely small, a probable result of cracks and fissures in the soil. In summary, the test results showed a non-uniform soil condition. Therefore, it may be concluded that the tile field was partly built

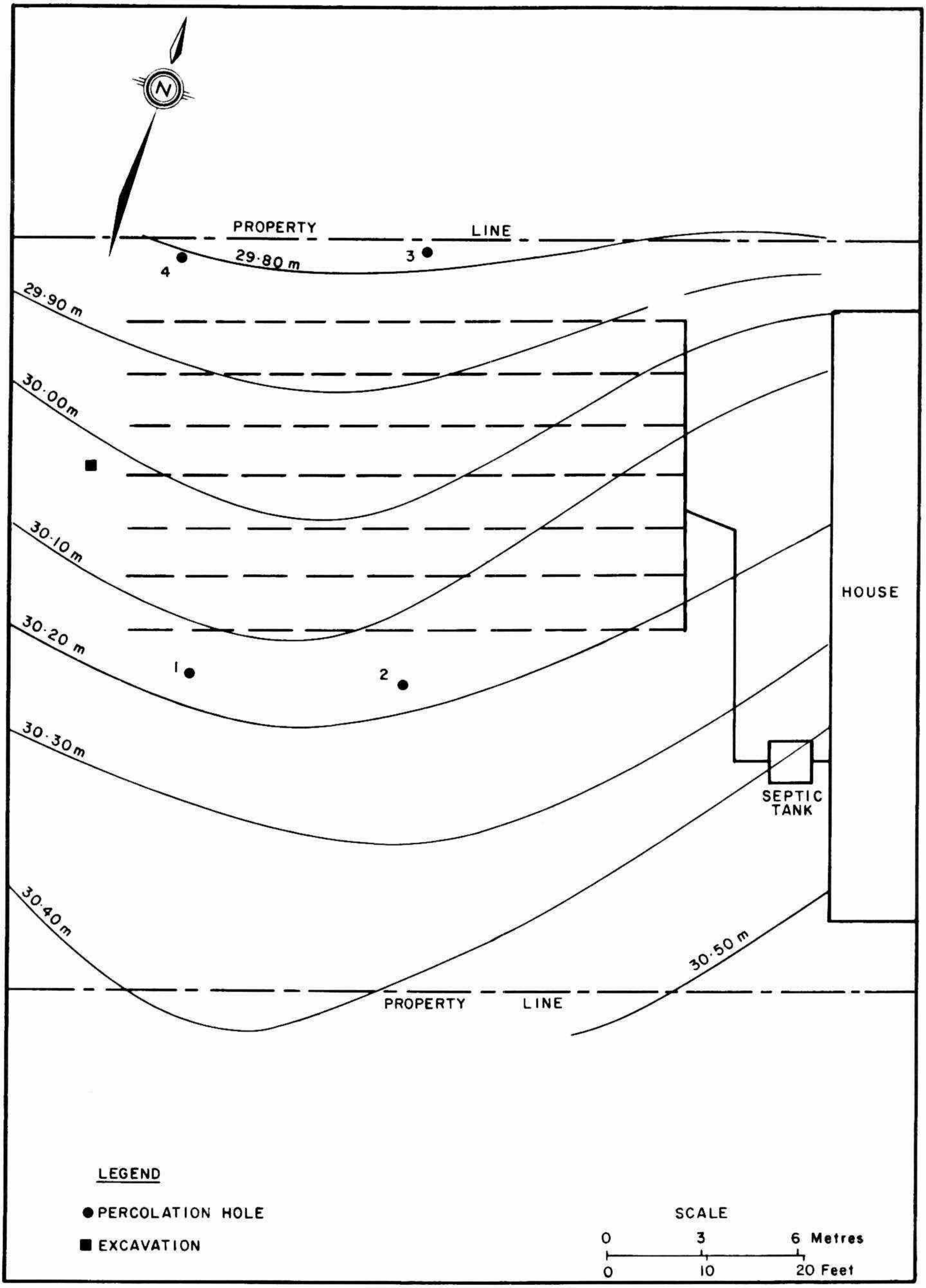

FIGURE 11: LAYOUT, TOPOGRAPHY AND LOCATIONS OF PERCOLATION HOLES AT SITE B2.

in reasonably permeable soils, and coupled with the low hydraulic loading rate of 10.5 $L/m^2/d$ (0.22 gals./ft.^{2}/day), the system would have experienced no difficulties in the disposal of the septic tank effluent.

3.2.3 Site B3

Figure 12 shows the topography of the site and the location of the tile field. As indicated by the ground surface contour lines, the site was quite flat. There were seven rows of tiles located at the depth of about 0.76 m (2.5 ft.). There were four people using the system and the hydraulic loading rate was 10.7 $L/m^2/d$ (0.22 gals./ft.^{2}/day).

Soil borings revealed that the subsoil was a clayey silt with 18 to 26% clay, 37 to 50% silt and 32 to 37% sand. The liquid limit of the soil was 36 and the plastic limit was 17. Block soil samples were taken from an excavation and hydraulic conductivity measurements were performed on the samples. Results are summarized in Table 4.

A total of four percolation tests were done on both sides of the tile field and the test data are summarized in Table 3.

Ten small copper pipes were installed above the tiles to measure the water level in the trenches. It was found that during the field investigation period (July to November 1977) the water level was not less than 0.46 m (1.5 ft.) below the ground surface. The water table was approximately 1.7 m below the ground surface in the vicinity of the tile field.

According to the owner of the dwelling, the septic tank-tile field experienced no operational difficulties all year round; and according to the water level measurements in the pipes installed in the trenches, the soil in the tile field apparently had no problems in absorbing the effluent from the septic tank during the field investigation period.

Referring to the results of the field percolation tests and the laboratory hydraulic conductivity measurements, the drainage or permeability characteristics of the soil appears to be very poor. This is not in agreement with the apparent satisfactory performance of the tile field at the site.

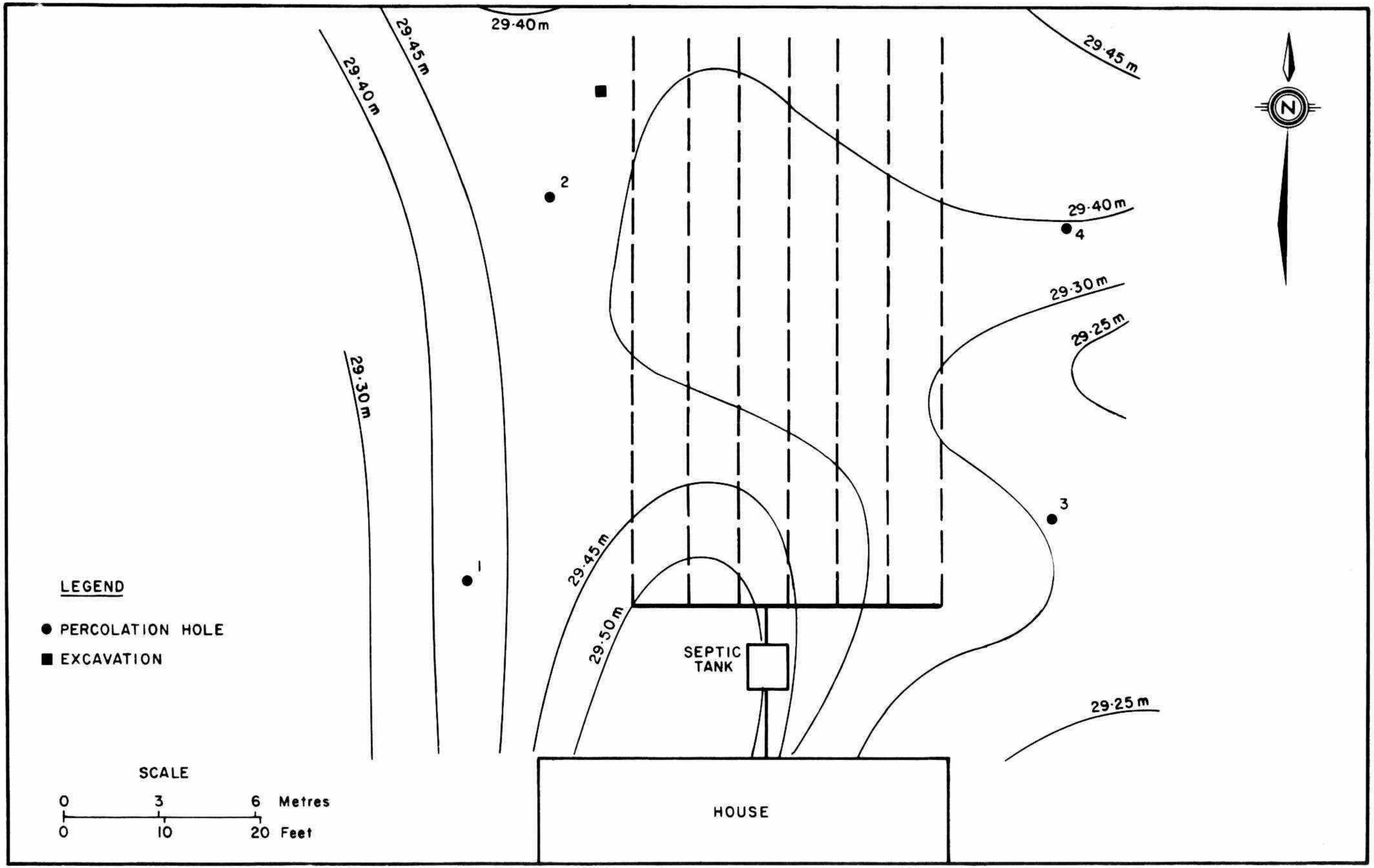

FIGURE 12: LAYOUT, TOPOGRAPHY AND LOCATIONS OF PERCOLATION HOLES AT SITE B-3

This inconsistency might be accounted for by the non-uniform nature of the soil, which could possess better drainage characteristics in some parts of the tile field. In addition, during the time of the field investigations, the effect of evapotranspiration might play a significant role in the disposal of the effluent from the trenches.

3.2.4 Site B4

The layout of the tile field and the contour of the ground surface are shown in Figure 13. (Note: There were only 91.4 m (300 ft.) of tiles at this site). The depth of the tiles was approximately 0.4 m (1.3 ft.) below the ground surface which sloped gently towards the south. The well points installed on the site indicated that the water table was at the depth of about 1.5 m (5 ft.) and the small copper pipes installed above the tile trenches showed that the trenches were dry. There were three people (2 adults and 1 child) using the system and the hydraulic loading rate on the tile field was 14.9 $L/m^2/d$ (0.31 $gals./ft.^2/day$).

The site was underlain by a few cm of top soil overlying a layer of brownish-grey clayey silt. The soil consisted of 22 to 37% clay, 43 to 51% silt and it was classified as a clay of medium plasticity (liquid limit = 56 and plastic limit = 23).

A total of three percolation tests were performed and the results are summarized in Table 3. The test holes were located near the end of the tiles because permission could only be obtained to do the tests in that area. A block sample was obtained from an excavation on the neighbour's property because it was not allowed to do the excavation on the test site. Two measurements of the hydraulic conductivity of the soil were done and the results are reported in Table 4.

During the time of the field investigation from July to November 1977, the tile field was working satisfactorily and showed no sign of ponding of septic tank effluent in the trenches, indicating that the soil had adequate adsorptive capacity for the septic effluent. The reasonably good performance of the tile field could be partly attributed to the low hydraulic

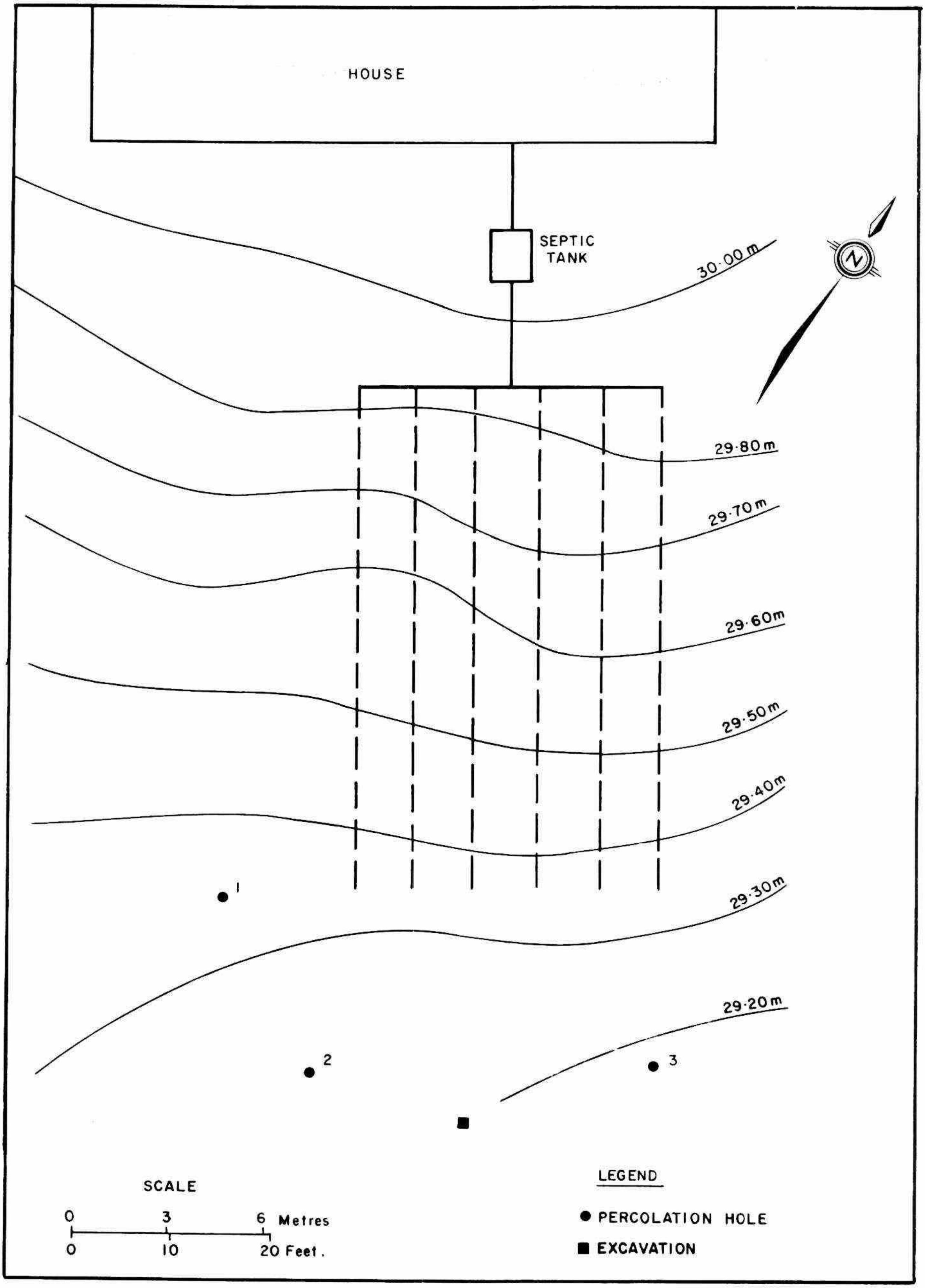

FIGURE 13: LAYOUT, TOPOGRAPHY AND LOCATIONS OF PERCOLATION HOLES AT SITE B4.

loading rate on the system and the climatic conditions at the time of the field investigation. However, the performance of the system did not appear to be substantiated by the percolation test results which suggested poor drainage conditions of the soil, but the hydraulic conductivity measurements on the soil samples suggested a reasonably good drainage characteristics of the soil. These apparent conflicting results may be explained by the non-homogeneous soil conditions at the test site. Referring to Table 3, the percolation time in hole 3 was much smaller than that in holes 1 and 2, which were located on one side of the tile field. It would seem probable that some area in the tile field was underlain by soil of poor drainage characteristics and some area was underlain by more permeable soil which was capable of absorbing the effluent from the septic tank.

3.3 Miscellaneous Sites

The remaining two of the twelve test sites were not located in any subdivision and were situated between Toronto and Barrie. These two individual sites will be discussed separately.

3.3.1 Site M1

This site was located on the outskirts of Georgetown (Town of Halton Hills). It is approximately 50 km (30 miles) west by northwest of Toronto. This site was used as an apple orchard with most of the area covered by mature apple trees. The topography of the site was quite flat with a gentle slope towards the south.

There were five people using the system (two adults and three children). The household had full plumbing conveniences including a dishwasher and a washing machine, all connected to the septic tank system.

The waste disposal system was installed by a contractor in 1967 and consisted of a cast iron septic tank and six rows of clay tiles (Figure 14). It was not possible to find any information on the design and the capacity of the tank. The tiles were located between rows of apple trees and were 46 cm (18 in.) below the ground surface. The length of each row of tiles was 13.7 m (45 ft.) giving a total length of 82.3 m (270 ft.) for all six rows. The

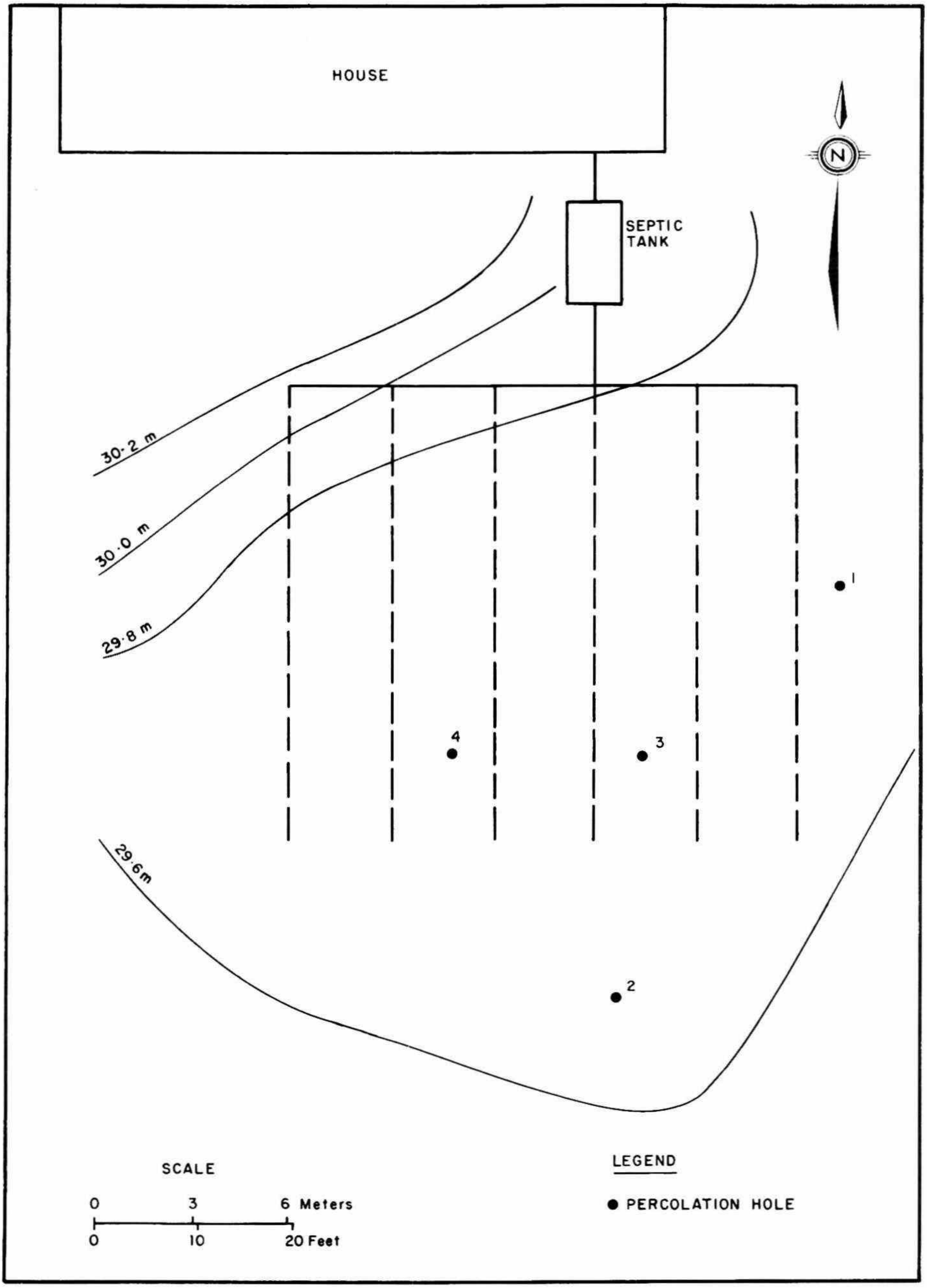

FIGURE 14: LAYOUT, TOPOGRAPHY AND LOCATIONS OF PERCOLATION HOLES AT SITE MI.

average hydraulic loading rate on the tile field was 22.8 $L/m^2/d$ (0.46 gals./$ft.^2$/day).

The site was underlain by about 0.4 m of black organic sandy silt overlying brown sandy silt material which consisted of 13 to 18% clay, 46 to 67% silt and 13 to 41% sand. No excavation was made to recover "undisturbed" soil samples because it was not possible to obtain this kind of soil samples in the sandy silt material. The location of the ground water table was established by well points and at the time of the field investigation (summer and fall, 1976), it was approximately 1 m below the ground surface.

Four percolation tests were done adjacent to the tile field and the results are tabulated in Table 5. It can be seen that the test results varied considerably but probably the average percolation time of the soil in the tile field area would be smaller than 24 min./cm (60 min./in.).

During the field investigation period, it was found that the soil in the tile field had adequate adsorptive capacity for the septic tank effluent. This conclusion was derived from field observations of the ground surface in the tile field area and information from the owner of the house. The operational success of the tile field was probably due to the relatively low hydraulic loading rate and reasonably good drainage characteristics of the soil (percolation time less than 24 min./cm).

3.3.2 Site M2

The site was located in the Town of Richmond Hill approximately 30 km (20 miles) north of Toronto. The dwelling was occupied by a retired couple who had lived there for 40 years. The topography of the tile field area was sloping at about 2.5% in the westerly direction (Figure 15).

The septic tank system was about 22 years old (as of 1976) at the time of the study and was built by the owner of the dwelling. There was no drawing available from the local health unit and the capacity of the septic tank was not known. The layout of the tile field as shown in Figure 15 was determined by probing into the ground. According to the owner, the original

TABLE 5 SUMMARY OF PERCOLATION TEST RESULTS OBTAINED FROM SITES M1 and M2

SITE	HOLE	PERCOLATION TIME (min/cm)	(min/in)
M1	1	96	245
	2	4	9
	3	28	71
	4	9	23
M2	1	85	215
	2	87	221

NOTE: All percolation holes were 0.6 m (2.0 ft) deep.

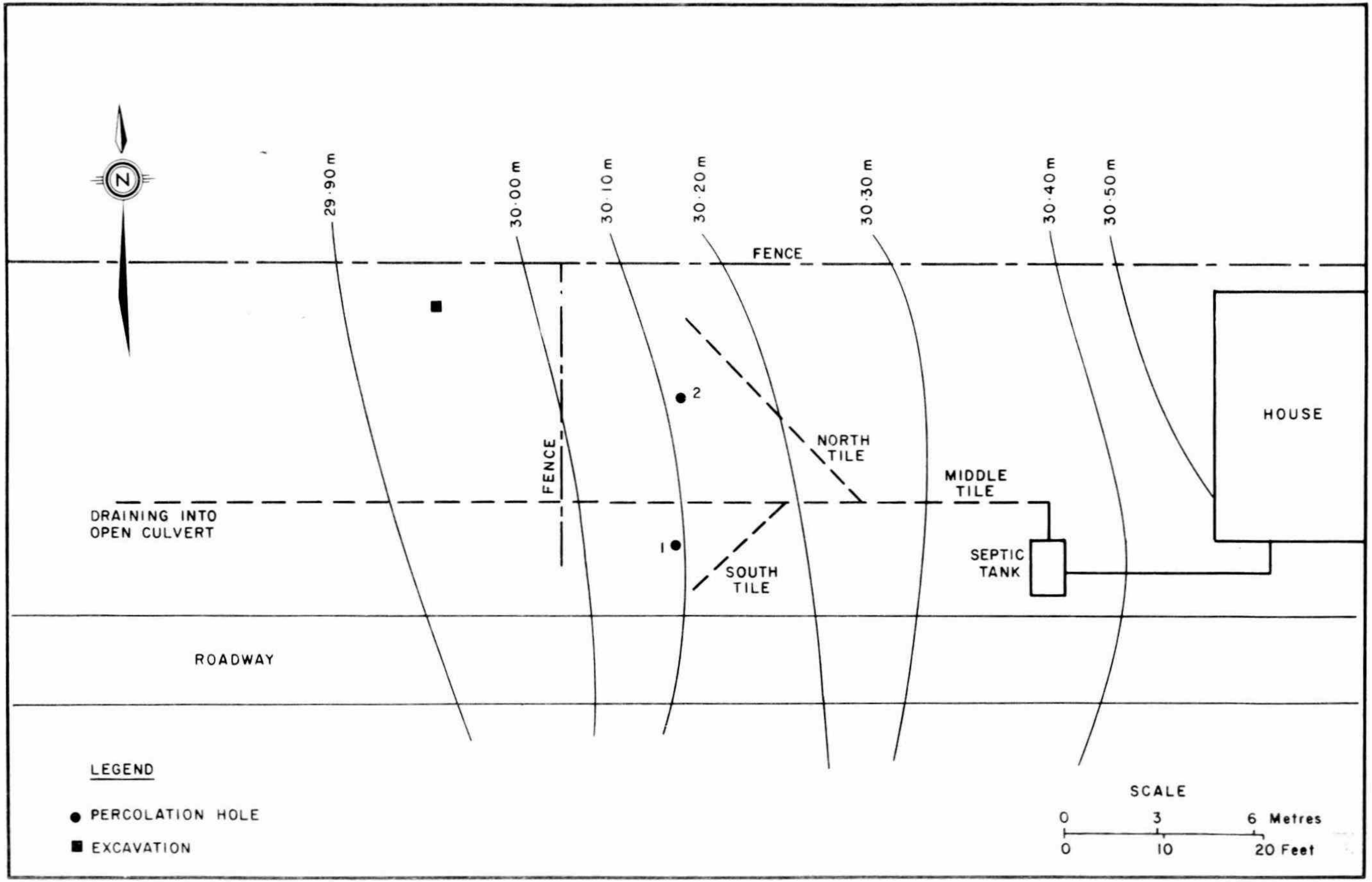

FIGURE 15: LAYOUT, TOPOGRAPHY AND LOCATIONS OF PERCOLATION HOLES AT SITE M2

part of the tile field did not seem to work properly and the system backed up occasionally. To alleviate the problem the owner extended the middle tile 13 m and exposed the end of the tile in a dug trench, leading into a road culvert. The tiles were located at shallow depths and the maximum depth was about 40 cm with the end of the middle tile being exposed to the ground surface (See Figure 16).

The tile field was constructed in soil consisting of 27 to 46% clay, 36 to 53% silt and 3 to 34% sand. The soil was classified as clay of medium plasticity (liquid limit = 48, plastic limit = 22). An "undisturbed" soil sample was taken from an excavation (note: permission could not be obtained to do the excavation closer to the tile field) for laboratory hydraulic conductivity tests. It was found that the hydraulic conductivity of the soil was equal to 1.7×10^{-4} cm/s (dry density = 1.41 g/cm^3, moisture = 26.7%). This relatively large value for the clayey silt was probably due to the soil structure which was blocky and easily breakable.

Two percolation tests were done in the vicinity of the tile field area and the results are summarized in Table 5.

The wetness of the soil above the tile trenches was measured with tensiometers in July 1976. It was found that the tile in the middle was quite dry with tensiometer readings ranging from 10 to 50 centibars. The tile trench on the south had two wet spots with zero readings and the trench on the north was wet in the end portion.

On the basis of the tensiometer readings and field observations, it was concluded that the tile field was not operating in a satisfactory condition. In order to explain the performance of the tile field, it is necessary to examine the profile of the three rows of tiles (Figure 16). The middle tile sloped down from the exit of the septic tank and then sloped upward and downward again. Also, the north tile had the steepest slope. Because of this arrangement and construction of the three rows of tiles, a larger portion of the septic tank effluent would likely be distributed into the north tile.

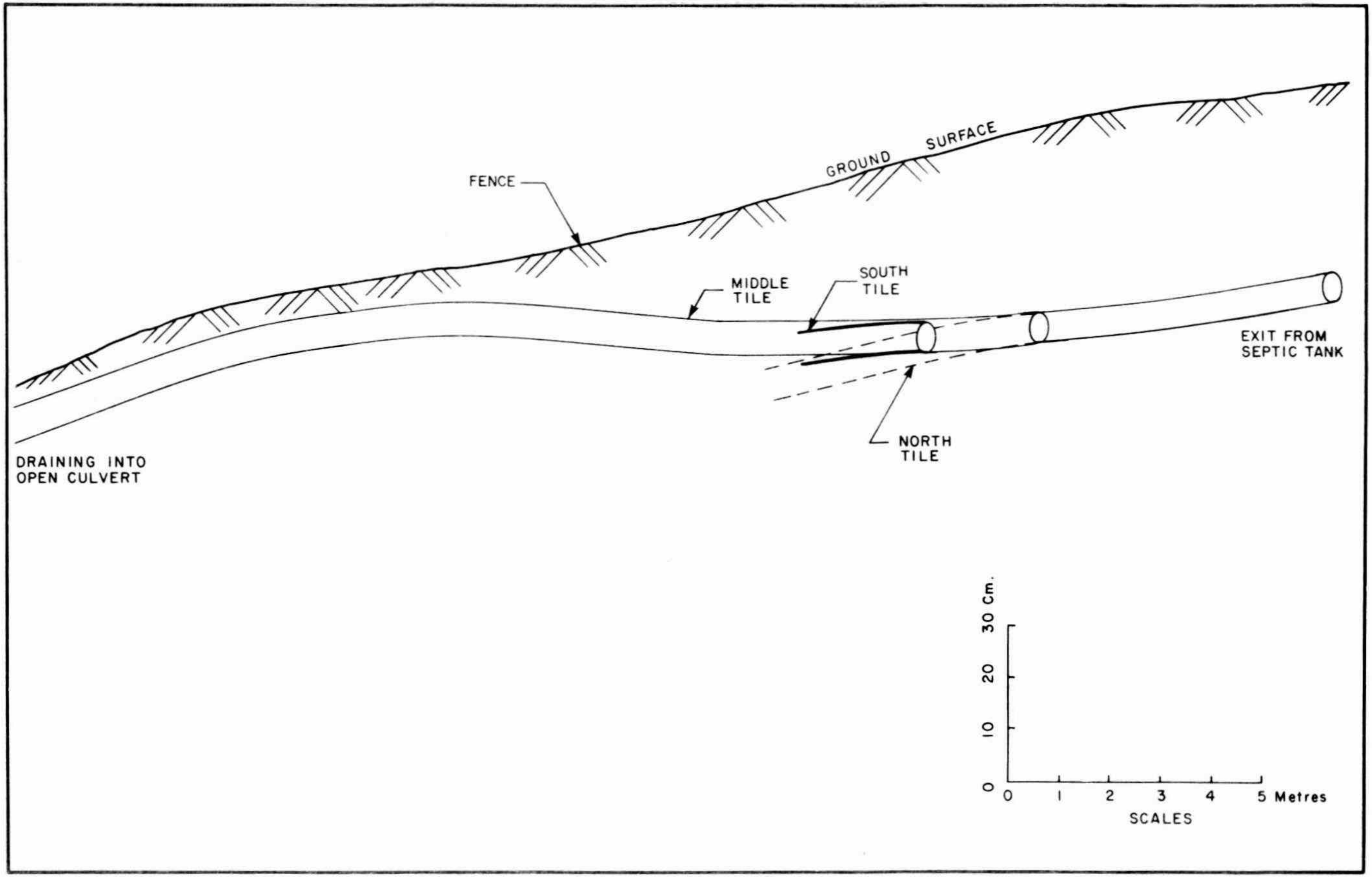

FIGURE 16: PROFILE OF TILES AT SITE M2.

Furthermore, it would be virtually impossible, under the gravity flow condition, for the septic tank effluent in the middle tile to reach the open culvert. In fact, the varying slopes of the middle tile would make the portion of tile closer to the road useless. If the total useful length of the three rows of tiles was used for the calculation of the hydraulic loading rate on the tile field, the average value would be equal to 33.4 L/m^2/d (0.67 gals./ft.^{2}/day) for the case of uniform distribution of effluent in the tiles. Under the actual condition, the distribution of flow was not uniform; and, therefore, the loading rate on the north tile would be greater than the average value. Referring to the percolation test results in Table 5, the percolation time of the soil in the tile field area was about 80 min./cm (200 min./in.), suggesting poor drainage characteristics of the soil. However, the laboratory hydraulic conductivity of the soil was in the order of 10^{-4} cm/s, which would indicate a soil of medium permeability. These apparent conflicting results may be explained by the non-uniform soil conditions at the site. Because the excavation was made in the area quite far away from the tile field, the percolation test results which were performed between the rows of tiles may be a better indication of the drainage characteristics of the soil in which the tile field was constructed.

In summary, the performance of the tile field was not entirely satisfactory because of: (i) poor installation of the tiles which caused uneven distribution of effluent and; (ii) soil with inadequate absorptive capacity for septic-tank effluent.

4. DISCUSSION

In this study, a total of twelve existing tile-field systems constructed in fine-grained soils were investigated for their adsorptive capacity for septic tank effluent. Because of the nature of the work, all the field tests were conducted on private properties and the permission of the owners was required. Consequently, on some testing sites, some of the scheduled tests could not be carried out and the locations for excavation in some cases were not as desirable as they should be. Furthermore, because the sites were covered with snow in the late fall and winter seasons of the year, the performance of the tile field during the cold seasons could not be studied on site. In spite of these practical limitations in the field investigative program, some interesting observations have been obtained.

4.1 Maximum Permissible Percolation Time (24 min/cm or 60 min/inch)

According to the regulations of many government agencies in Canada and the United States, if a soil has a percolation time ("t" time) in excess of 24 min/cm (60 min/inch), the soil would be considered to be "impervious" and therefore not recommended for the installation of a conventional tile-field system. This percolation time limit is to some extent arbitrary.

In area A, six sites were investigated and it was found that sites A1, A2 and A3 were satisfactory in the sorption of the septic tank effluent. As shown in Table 1, the percolation time ("t" time) of the soil around the tile field at site A1 varied from 6 to 23 min/cm (15 to 59 min/inch.) (test results in holes 1 to 6). At site A2, the "t" time of the soil at 1.2 m (4.0 ft., approximate depth of the tiles) was about 43 min./cm (110 min./inch.). At site A3, the "t" time of the soil near the tile field varied from 4 to 59 min./cm (9 to 150 min./inch. in holes 3, 4, 5 and 6). The performance of the tile fields at sites A4, A5, and A6 was not satisfactory, at least during some months of the year. Among several factors, the main one contributing to the failure was poor soil drainage characteristics as reflected by the large values of the "t" time (table 1).

In area B, the four tile fields studied were satisfactory in the sorption of the septic tank effluent during the time of the field investigations (summer and fall seasons). However, as indicated in Table 3, the "t" times for the soils at these sites were generally quite large. It is believed that during the warmer months the effect of evapotranspiration alone could not account for the successful operation of the systems. According to the results of Brandes (1978) and Rugen et al (1977), it may be assumed that the amount of water which can be removed by evapotranspiration from the tile field was 4.9 $L/m^2/d$ (0.1 $gal/ft.^2/day$). At the 4 test sites, the hydraulic loading rates varied from 9.8 to 14.7 $L/m^2/d$ (0.2 to 0.3 $gal/ft.^2/day$) and it may be concluded that the soils were capable of absorbing at least 4.9 $L/m^2/d$ of effluent.

At site M1 the tile field worked quite satisfactorily because a large portion of the tile field was probably located in soils with "t" time smaller than 24 min./cm. The tile field at site M2 did not function too well and the large "t" time of the soil was one of the contributing factors.

In Figure 17, the values of the "t" time of the soils at the twelve sites are plotted against the hydraulic loading rate on the tile field at each site. Referring to Figure 17, the four tile fields at sites A4, A5, A6 and M2 which had operational difficulties were installed in soils having "t" time values greater than 45 min./cm (excepting at site A6, the "t" times of the soil were extremely variable and there were two low "t" time values). On the other hand, the tile fields installed in soils with "t" time less than 45 min./cm generally worked satisfactorily with a hydraulic loading rate less than 23 $L/m^2/d$. As the "t" time value increases, the probability (or risk) of failure of the tile field also increases.

A relationship between the tile field loading rates and the "t" time was proposed by Ryon in the 1930's (Federick, 1948). Figure 18 shows this relationship for "t" times up to 30 min./cm (75 min./inch.). On the basis of extrapolating the data in Figure 18 and the results contained in Figure 17, it is recommended that soils with "t" times equal to 40 min./cm

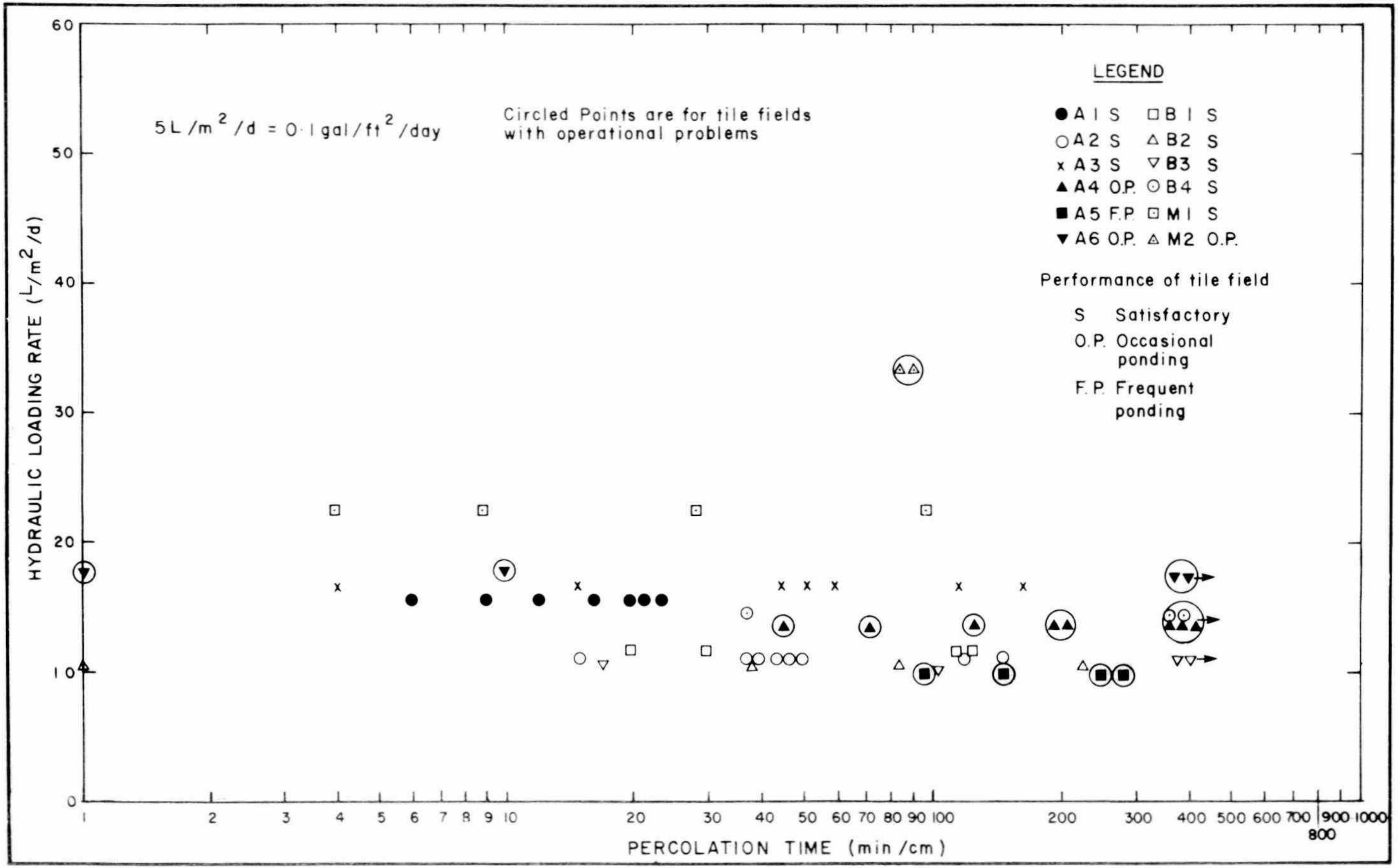

FIGURE 17: HYDRAULIC LOADING RATES ON TILE FIELDS Vs. PERCOLATION TIME OF SOILS

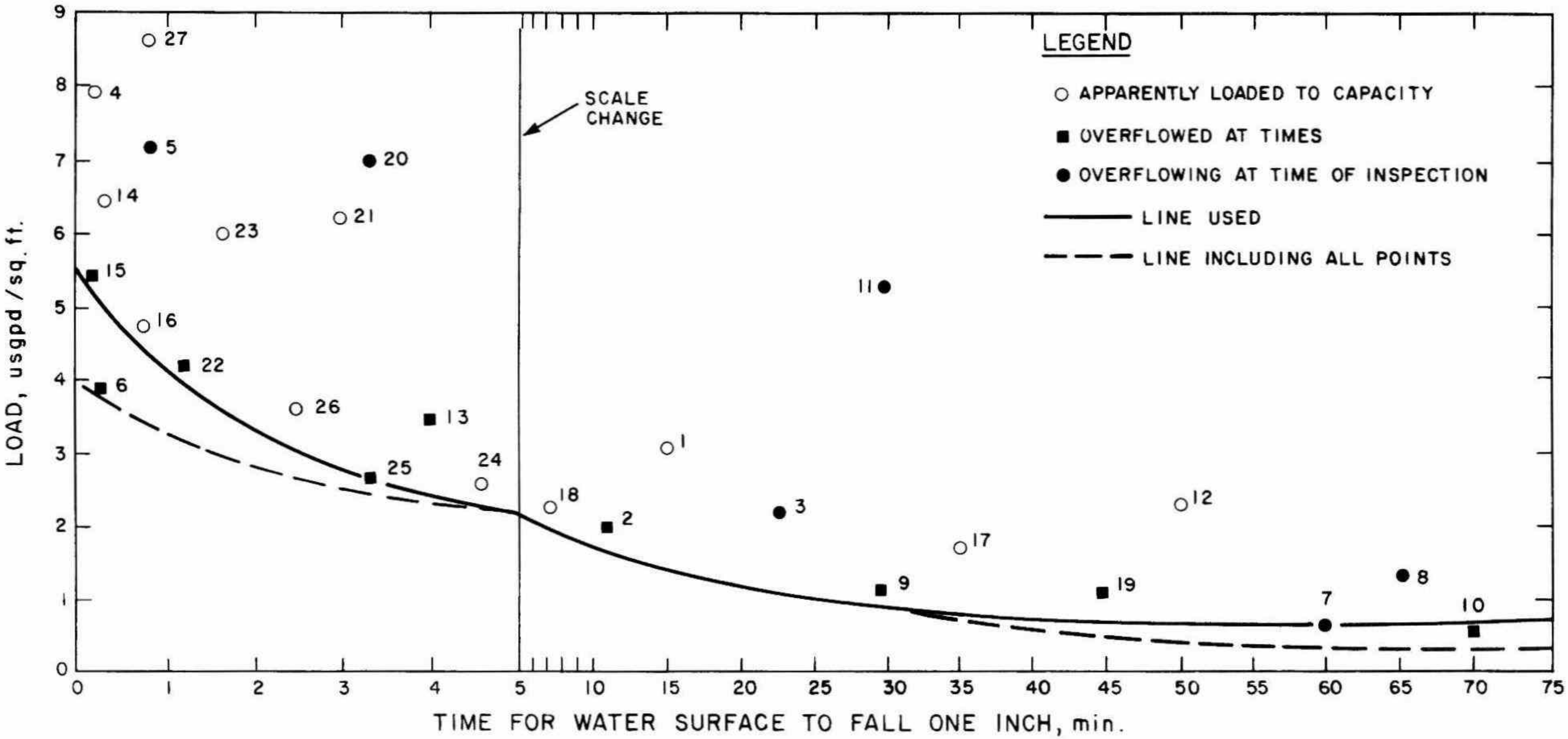

FIGURE 18: RELATIONSHIP OF TILE FIELD LOADING RATES TO PERCOLATION TEST RATES. (AFTER McGAUHEY AND KRONE, 1967)

(100 min./inch.) would still be acceptable for the installation of the conventional tile field provided that the hydraulic loading rate is less than 15 $L/m^2/d$ (0.3 $gals/ft.^2/day$).

4.2 Use of Soil Maps

It has been suggested that soil maps are useful in deciding the suitability of the soils for the installation of tile field systems (U.S.D.A., 1961; Morris et al, 1962; Seglin, 1965; Huddleton and Olson, 1967). The experimental data collected from this project did not seem to support this idea. The study areas A and B used in the investigation were very small on a soil map, and yet the on-site percolation test results as well as the laboratory hydraulic conductivity measurements varied significantly both in terms of locations and depths. However, on the soil map, the soils located in Areas A and B were classified as one type of material. It is felt that although soil maps may be useful in deciding the suitability of sands for conventional tile fields, they would be of little use for fine-grained soils, such as silts and clays.

4.3 Use of Soil Data for Evaluating Soil Suitability

Generally, soils composed of fine-grained particles are less permeable than soils made up of coarse-grained particles. In may cases, therefore, sands are more permeable than silts and clays. If this correlation between soil drainage characteristics and soil particle sizes were true for all fine-grained soils. it would be quite straightforward to evaluate the suitability of fine-grained soils for the installation of tile fields. However, because fine-grained soils are structured soils, the correlation of drainage characteristics and soil particle size is poor (Chan, 1975). Frequently, the structure of a fine-grained soil (e.g. hair-line cracks, fissures, fine worm holes) can have a very significant influence on the drainage characteristics of the soil, and the influence of the structure can over-shadow the particle size effect. In Figure 19, the particle distribution curves of some typical soil samples obtained from the six sites in Area A are plotted. The curves indicate that the soil at site A1 is coarser than the soil at site A5, which can be related to the better drainage characteristics (smaller "t" time) of

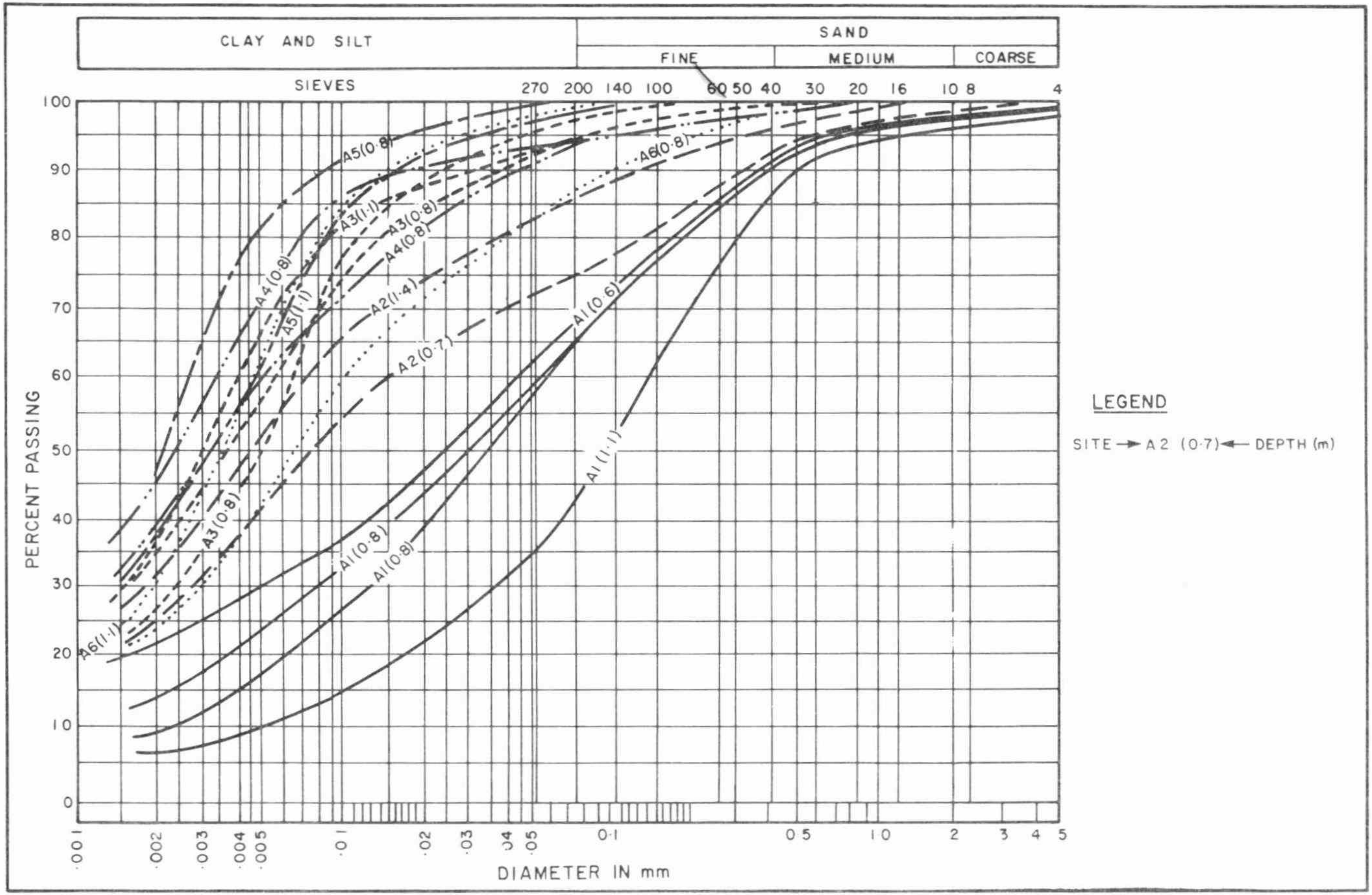

FIGURE 19: PARTICLE SIZE DISTRIBUTION CURVES OF SOIL SAMPLES FROM SITES A1 TO A6.

the soil in situ and the more satisfactory performance of the tile field at site A1. However, the particle size distribution curves of the soils from the other four sites in Area A cannot be correlated successfully with the drainage characteristics of the soils and the performance of the tile field. In Figure 20, the particle size distribution curves for some soil samples collected from the four sites in Area B and sites M1 and M2 are presented. As discussed in Section 3, the performance of tile fields at these sites was quite variable and the particle size data in Figure 20 are not particularly useful in pointing out the soils in which tile fields performed satisfactorily.

Besides soil particle size, another soil parameter which is frequently used to relate the drainage characteristics of soils is the hydraulic conductivity (permeability). Hydraulic conductivity is a coefficient which indicates how easily water can percolate through the soil. In this project, soil samples were obtained from excavations at the test sites for laboratory hydraulic conductivity tests. The test results are summarized in Tables 2 and 4. In most cases, only one excavation was done at one site and two hydraulic conductivity tests were performed on the soil samples. The test results indicate a significant variation in the values of the hydraulic conductivity of the soils (i.e. 10^{-4} to 10^{-8} cm/s) at different sites and sometimes at different depths in the same excavation. Because of the variations in the test results, it was difficult to correlate the hydraulic conductivity measurements with the on-site performance of the tile fields. However, on the basis of the very limited test data available, it appears that tile fields constructed in soils with the hydraulic conductivity in the order of 10^{-5} cm/s or larger would more likely perform satisfactorily. It should be stressed that the suggested value of the hydraulic conductivity (10^{-5} cm/s) is an approximate one and should be used with caution. Furthermore, the hydraulic conductivity test should be performed on soil samples obtained from an excavation with the apparatus similar to the one described in this report. Past experience has indicated that a fine-grained soil sample obtained with a shelby tube would give erroneous hydraulic conductivity results.

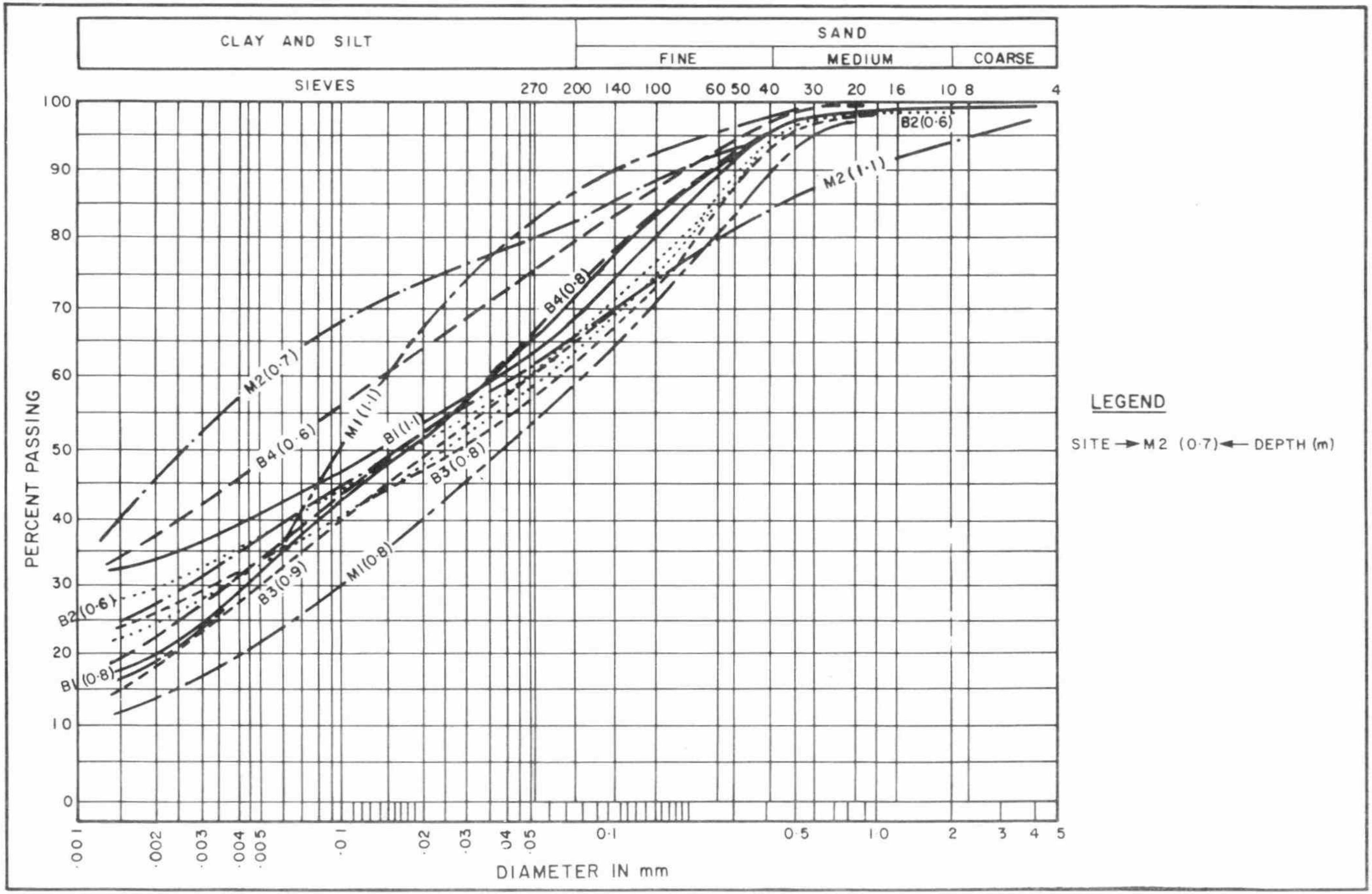

FIGURE 20: PARTICLE SIZE DISTRIBUTION CURVES OF SOIL SAMPLES FROM SITES B1 TO B4, M1 AND M2.

In summary, the time involved in performing the hydraulic conductivity tests and taking the soil samples, the generally large variations in the test results and the poor correlation between the hydraulic conductivity and the performance of the tile field tend to reduce the practical usefulness of the hydraulic conductivity for evaluating the drainage characteristics of the soils.

In Table 6 and Figure 21 the plasticity test results (liquid limit, plastic limit and plasticity index) are presented. According to the data, the soils at the test sites can be classified as clays of low, medium and high plasticity (Terzaghi and Peck, 1967). Generally, it is believed that the poor performance of a tile field may be related to the high plasticity of the soil. This concept is examined with the test results on the soil samples obtained from the sites. Referring to Figure 21, there is no clear correlation between the plasticity of the soil and the performance of the tile field installed in that soil. For example, the soil at site A3 has a higher plasticity index and higher liquid limit than the soils at site A4 and site A5, and yet the performance of the tile field at site A3 was much more satisfactory than the systems at the other two sites. Therefore, it can be concluded that the use of soil plasticity data for predicting the performance of a tile field is questionable.

TABLE 6 SUMMARY OF PLASTICITY TEST DATA

SITE	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX
A1	-	-	-
A2	37	20	17
A3	41	21	20
A4	33	18	15
A5	34	19	15
A6	39	20	19
B1	40	20	20
B2	38	17	21
B3	36	17	21
B4	56	23	33
M1	-	-	-
M2	48	22	26

NOTE: Tests were not done on soils from sites A1 and M1 because the soils were practically non-plastic. (i.e. little cohesion).

Plasticity Index = Liquid Limit - Plastic Limit

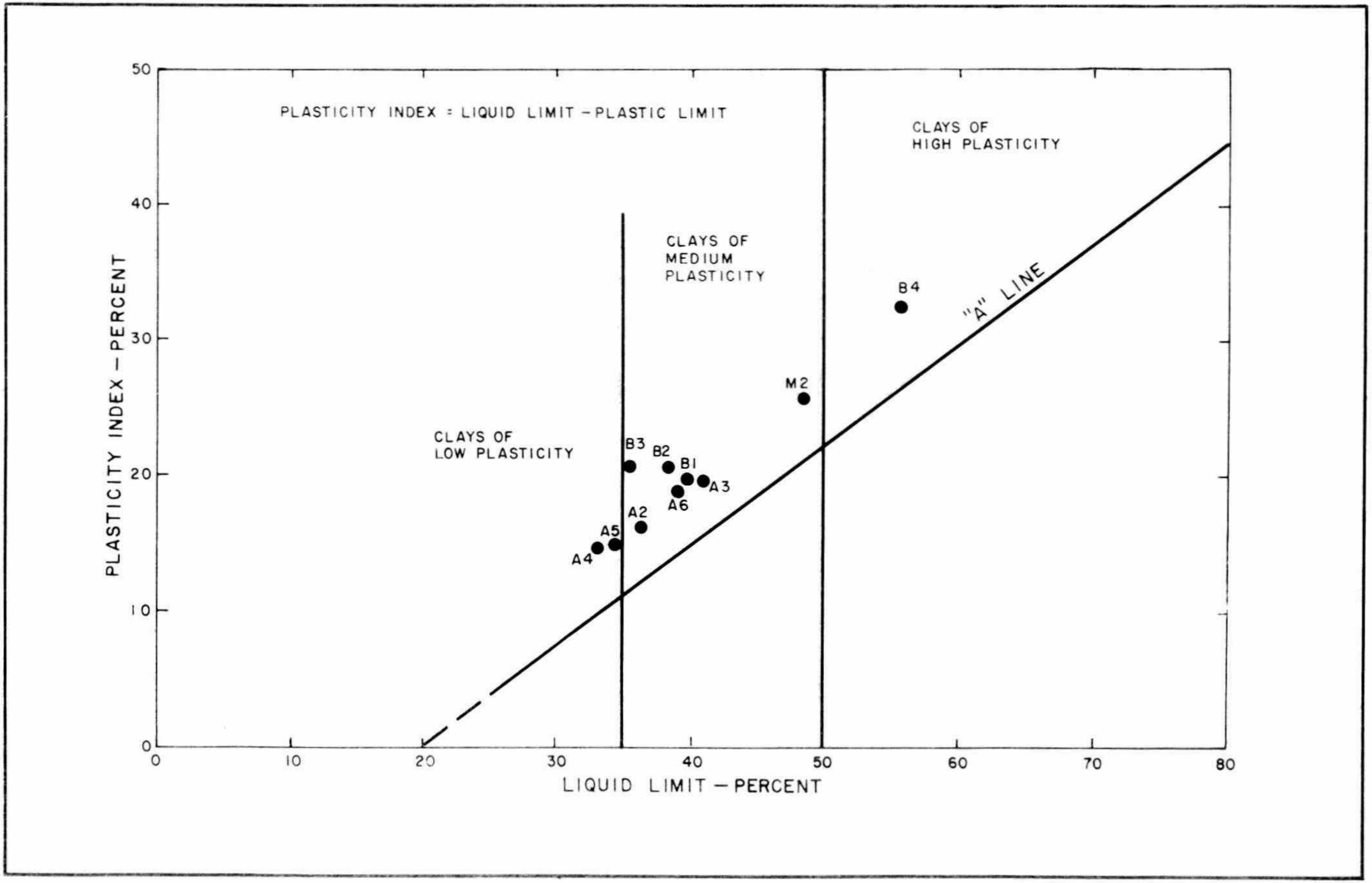

FIGURE 21 : SUMMARY OF PLASTICITY DATA ON THE PLASTICITY CHART

5. CONCLUSIONS AND RECOMMENDATIONS

From the field studies of twelve existing tile fields constructed in fine-grained soils, a number of conclusions can be drawn:

(1) The tile fields constructed in soils with a percolation time ("t" time) less than 24 min./cm (60 min./inch.) functioned satisfactorily. However, some tile fields with "t" time greater than the 24 min./cm limit also operated without difficulties.

On the basis of the limited field data, it is recommended that the maximum permissible "t" time be increased to 40 min./cm (100 min./inch.) from 24 min./cm (60 min./inch.) if the hydraulic loading rate does not exceed 15 L/m^2/d (0.3 gals./ft.^{2}/day).

Despite the shortcomings of the field percolation test, it appears that the test is a reasonable means for the evaluation of the suitability of fine-grained soils for the installation of tile fields.

(2) Soil maps are not too useful in the evaluation of the drainage characteristics of the soils because of the significant variability of the drainage characteristics of the soils even in a small area (e.g. a few hectares), especially where fill has been used extensively or the soil structure altered as in many subdivisions.

(3) The hydraulic conductivity of the soil may give a crude estimate of the drainage characteristics of the soil at the potential site. However, there are many practical limitations in using this soil parameter for the design of tile fields.

(4) The use of soil particle size data to estimate the drainage characteristics of fine-grained soils is not reliable because the effect of soil structure can over-shadow the effect of soil particles.

(5) The use of soil plasticity data for predicting the performance of a tile field is not suitable.

(6) The success in the operation of a tile field does not solely depend on the soil characteristics at the site. Other design considerations, such as surface drainage, must be taken into account in the design of the tile field.

(7) From the field observations, some guide lines for the design of tile fields are proposed:

(a) The surface drainage in the tile field area should be properly designed so that the surface runoff can drain away from the tile field.

(b) The distribution of the septic tank effluent in the tiles should be uniform. Non-uniform distribution of the effluent can result in over-loading of some of the tiles, which may cause surface ponding. (Example: Site M2).

(c) Compaction of the soil above the tiles should be avoided if possible. The compacted soil would be much less permeable than the natural undisturbed soil at the same site.

(d) The soil profile of the proposed site should be investigated to the depth of not less than 2 m. Any "impervious" layer near the ground surface should be noted and taken into account in the design consideration.

(e) A total of four field percolation tests are recommended for the evaluation of the suitability of the soil for the installation of a tile field. Because the "t" time results often vary significantly, it would be meaningless to average the test data and use the average value for design. Instead, it is suggested that the percentage of the area at the site with a certain range of "t" time (e.g. 30-40 min.) be estimated for design purpose. If it is practically feasible, the area with the smallest "t" time should be used for the construction of the tile field.

REFERENCES

A.S.T.M., 1970. Special Procedures for Testing Soil and Rock for Engineering Purposes. STP 479. American Soc. for Testing and Materials.

Brandes, M. 1978. Effect of Precipitation and Evapotranspiration on Filtering Efficiency of a Wastewater Disposal System. Report No. W70, Applied Sciences Section, Pollution Control Branch, Ministry of the Environment, Toronto, Ontario.

Chan, H.T. 1975. Study on the Feasibility of Correlating Percolation Time with Laboratory Permeability. Report No. S57, Applied Sciences Section, Pollution Control Branch, Ministry of the Environment. Toronto, Ontario.

Chan, H.T. 1976. Effect of Hole Size on Percolation Rate in a Field Percolation Test. Report No. S60, Applied Sciences Section, Pollution Control Branch, Ministry of the Environment, Toronto, Ontario.

Federick, Joseph C. 1948. Solving Disposal Problems in Unsewered Areas. Sewage Works Engineering, Vol. 19, No. 6, pp. 282-293.

Hoffman, D.W., Wicklund, R.E., and Richards, N.R. 1962. Soil Survey of Simcoe County, Ontario. Report No. 29, published jointly by the Research Branch, Can. Dept. of Agriculture and the Ontario Agric. College.

Huddleton, J.H., and Olson, G.W. 1967. Soil Survey Interpretation for Subsurface Sewage. Soil Science, Vol. 104, No. 6, pp. 401-409.

McGauhey, P.H., and Krone, R.B. 1967. Soil Mantle as a Wastewater Treatment System. Final Report. SERL Report No. 67-11, University of California, Berkeley.

Ministry of the Environment. 1974. Septic Tank Systems, Toronto, Ontario.

Morris, John G., Newbury, Raymond L., and Bartelli, Lindo J. 1962. For Septic Tank Design, Soil Maps can Substitute for Percolation Tests. Public Works, February Issue, pp. 106-107.

Rugen, Mark A., Lewis, David A., and Benedict, Irvin J. 1977. Evapotranspiration, A Method of Disposing of Septic Tank Effluent. Report No. G 75-185. RABA and Associates, Inc., San Antonio, Texas.

Seglin, Lester L. 1965. Comparability of Soil Survey and Percolation Test Data. Journal of Soil and Water Conservation. Vol. 20, pp. 167-168.

Terzaghi, K., and Peck, R.B. 1967. Soil Mechanics in Engineering Practice (2nd Edition), John Wiley and Sons, New York.

U.S.D.A. (U.S. Dept. of Agric.). 1961. Soils Suitable for Septic Tank Filter Fields. Soil Conservation Service, Agriculture Information Bulletin, No. 243.